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PHYSICS
Annual Report

July 1970 through June 1971

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Contents

PHYSICS RESEARCH

*Preceding Physics Reports: UCRL-20120, UCRL-19415

EXPERIMENTAL PHYSICS, GROUP A

Frank T. Solmitz in charge

K82 EXPERIMENT

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

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

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

More than 1500 events with a visible K^0 were found. Detailed fits to the reaction have been made using the Bardacki-Ruegg generalization of the Veneziano 5-point function, with several different sets of assumptions.[1] We find that the quality of the fits depends to a large degree on the choice of kinematic factors, and we also find that a good fit can be obtained only by using five adjustable parameters, multiple trajectories, and several kinematic factors. (Submitted to Phys. Rev.)

Virtual π^+p Scattering

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

Low-Mass $K\pi\pi$ Systems

A study has been made of the $K\pi\pi$ system in the region of the Q enhancement (1.1 to 1.5 GeV) in the reactions $K^+p \to pK^0\pi^0\pi^+$. A two-peak structure is observed: a Q_L with $M_L \sim 1.26$ GeV and $\Gamma_L \sim 0.12$ GeV, and Q_H with $M_H \sim 1.42$ GeV and $\Gamma_H \sim 0.08$ GeV. The $K_N(1420)$ does not account for the Q_H. Performing Dalitz-plot fits, we find that the Q decays into $K_V(890)\,\pi$, $\rho(765)\,K$, and $\epsilon(700)\,K$. This work will be published soon.

Quasi-Three-Body Final States

The mass spectra of the reactions $K^+p \to pK^+\phi$, $\phi \to K^-K^+$, and $K^+p \to pK^+\omega$, $\omega \to \pi^+\pi^-\pi^0$ are under investigation. Low-mass enhancements in $K\phi$, $K\omega$, and $p\omega$ are observed.

$K\pi$ Scattering

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

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1. Victor Waluch, Stanley Flatté, Jerome H. Friedman, and Denis Sivers, A Detailed Comparison of the Generalized Veneziano Model with Data on $K^+p \to \pi^+pK^0$ at 12 GeV/c, Lawrence Radiation Laboratory Report UCRL-20107, Feb. 1971.

K70 EXPERIMENT

Robert D. Tripp

In collaboration with the University of Chicago, we are analyzing 600 000 pictures taken in the 25-in. hydrogen bubble chamber with a K^- beam at different momenta from 0.87 to 1.0 GeV/c. The purpose of the experiment is to study in more detail the formation of Y^*_1s in this energy region, as well as to study the sequential reactions:

$$K^-p \rightarrow \Sigma(1765) \rightarrow \Lambda(1520) + \pi$$
$$\rightarrow \Sigma(1385) + \pi.$$

Scanning at EFINS and first measurements on the Spiral Reader at LBL have been completed. Analysis is in progress.

ANTIPROTONS IN DEUTERIUM

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

This study of antiproton interactions in deuterium is being done by a collaboration of three Italian laboratories (Padua, Pisa, Turin) with LBL physicists. The CERN 81-cm bubble chamber was exposed to antiprotons with momenta between 1.0 and 1.6 GeV/c, yielding 182 000 events. First and second measurements of these events have been completed on the Spiral Reader, and the data are now being analyzed at LBL and in Italy. In a study of the reaction $\bar{p}n \rightarrow \pi^+\pi^-\pi^-$ between 2.08 and 2.29 GeV c.m. energy, we found that the population of the 3π Dalitz plot (a total of 2328 events at all energies) is strongly nonuniform and shows a structure that can be qualitatively interpreted with simple Veneziano-type formulae. The moments of the angular distributions of the three-pion plane were also examined.[1] A study of the total cross section is in progress.

1. A. Bettini, M. Cresti, M. Mazzucato, L. Peruzzo, S. Sartori, G. Zumerle, M. Alston-Garnjost, R. Huesman, R. Ross, F. T. Solmitz, L. Bertanza, R. Carrara, R. Casali, P. Lariccia, R. Pazzi, G. Borreani, B. Quassiati, G. Rinaudo, M. Vigone, and A. Werbrouck, The Annihilation $\bar{p}n \rightarrow n\pi^+\pi^-\pi^-$ Between 1.0 and 1.6 GeV/c and Its Comparison with the Veneziano Model, Nuovo Cim. 1A, 333 (1971).

π^-p INELASTIC REACTIONS

Arthur H. Rosenfeld, Gerard Smadja, David J. Herndon, Larry Miller, Ronald Longacre (LBL); Roger Cashmore, David Leith (SLAC)

A systematic study of π^-p inelastic interactions from threshold to 2 GeV/c is being carried out by LBL and SLAC, based on about 85 000 $N\pi\pi$ events from several bubble chambers.[1] We have undertaken two analyses:

a) Our main effort has been to fit an extended isobar model in which we write the T-matrix element $T_{I,J}P \equiv T_k$ for each partial wave k as

$$T_k(N\pi\pi) = a_{k\Delta}\, T_{k\Delta}(\Delta\pi) + a_{k\rho}\, T_{k\rho}(N\rho) + a_{k\sigma}\, T_{k\sigma}(N\sigma). \quad (1)$$

b) In parallel with this ambitious program, we made a simpler fit to the data in the Δ^- band only:

$$T_k(N\pi\pi) = \alpha_k\, T_k(\Delta\pi). \quad (2)$$

We have published two fits to this Δ^- model in the 1688-MeV region, each with resonant D_{15} and F_{15} waves, plus background.[2]

We have now developed a general program for maximum likelihood fits to Eq. (1), and have obtained fits using 50 000 $N\pi\pi$ events between 1640 and 1800 MeV. The events were divided into six energy-bins, and independent fits were made to the model in each bin. We permit 60 "waves" (combinations of partial waves and final-state resonances), but get respectable χ^2 with only 20 to 30 waves. Our only satisfactory solution does not agree very well with either of the solutions to Eq. (2). For further details see the thesis of Larry

Miller.[3]

As a byproduct, we have also published a study of 80 000 elastically scattered events.[4]

1. A. D. Brody et al., Experimental Results on the Reactions $\pi^- p \to \pi\pi N$ in the c.m. Energy Range 1400-2000 MeV, Stanford Linear Accelerator Center Report SLAC-PUB-911 and Lawrence Radiation Laboratory Report UCRL-20856, June 1971; also, Supplement 1: Tables and Plots of Momenta of Angular Distributions.
2. A. D. Brody et al., The Reaction $\pi^- p \to \pi^\pm \Delta^\mp$ at CMS Energies 1640-1760 MeV, Phys. Letters 34B, 665 (1971).
3. L. R. Miller, Isobar Model Fit to the Reaction $N\pi \to N\pi\pi$: Fitting Procedures and Fits at 1.7 BeV (Thesis), Lawrence Berkeley Laboratory Report LBL-38, Sept. 1971.
4. A. D. Brody et al., $\pi^- p$ Elastic Scattering in the CMS Energy Range 1400-2000 MeV, Phys. Rev. D3, 2619 (1971). Two supplements have also been printed, but are not to be published: Tables of Cross Sections and Polynomial Coefficients, Supplement 1 to SLAC-PUB-789 and UCRL-20223; and A Comparison of the Results of Elastic Scattering Phase Shift Analyses, Supplement 2 to SLAC-PUB-789 and UCRL-20223.

π66 EXPERIMENT

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

$\pi^+ d$ Interactions from 2.7 to 4.2 GeV/c

Orin L. Dahl and Paul L. Hoch

We are studying about 20 000 strange-particle production events (with a visible Λ or K^0 decay). The rest of the 2.7- to 4.2-GeV/c exposure is being analyzed at Purdue and Illinois.

We have investigated certain OME-forbidden reactions, using data from this experiment and our previous $\pi^- p$ exposure. We have measured the electromagnetic mass difference in the $K^*(890)$ to be $\Delta m \equiv m(K^{*0}) - m(K^{*\pm}) = -3.6 \pm 4.0$ MeV. A report on these and other aspects of this exposure is being prepared.

$\pi^+ d$ Interactions from 1.1 to 2.4 GeV/c

Orin I. Dahl and Paul L. Hoch

The reaction $\pi^+ d \to (p)\, p\pi^+\pi^-\pi^0$ has been studied in a 264 000-picture bubble-chamber experiment with pion beam momentum between 1.1 and 2.4 GeV/c. The most significant features of the final state are production of η and ω mesons in the reactions

$$\pi^+ n \to \eta p,$$
$$\pi^+ n \to \omega p.$$

The η production characteristics are well described by a Reggeized A_2-exchange model using Veneziano-type residue functions. The ω production and decay characteristics have been analyzed, and it is found that a ρ-exchange model with absorptive corrections is inadequate to describe the data.[1]

1. J. S. Danburg, M. A. Abolins, O. I. Dahl, D. W. Davies, P. L. Hoch, J. Kirz, D. H. Miller, and R. K. Rader, Production and Decay of η and ω Mesons in the Reaction $\pi^+ d \to (p)\, p\pi^+\pi^-\pi^0$ Between 1.1 and 2.4 GeV/c, Phys. Rev. D2, 2564 (1970).

P65 EXPERIMENT

Eugene Gellert

An exposure of the 72-in. hydrogen bubble chamber to protons at 5.5 and 6.6 GeV/c was made in 1965. Using this film, we are studying the inclusive reactions for π^-, π^+, p, and n production for all nonstrange topologies (2, 4, and 6-prongs) at 6.6 GeV/c. A preliminary paper[1] discussed the case of single-particle proton distributions for 2- and 4-prongs; this is being extended to the above particles, and to models other than that of Krisch.

The study of the reaction $pp \to pp\pi^+\pi^-$ has

difference. The results are consistent with CPT invariance and with the values of the mixing parameters determined by means of weak interactions. Other absolute cross sections and ratios of cross sections for the $K^0_L p$ and $\bar{K}^0 p$ systems are also given in the same publication. [1]

1. G. W. Meisner and F. S. Crawford, Interactions of Neutral K Mesons with Hydrogen, Phys. Rev. D3, 2553 (1971).

SPARK CHAMBERS AND COUNTER STUDIES

Orin I. Dahl, Morris Pripstein, and Michael Wahlig

Neutral Final States in $\pi^- p$ Interactions

In collaboration with members of the Kenney-Helmholz group, a series of spark-chamber experiments has been performed at the Bevatron to study various neutral final states produced in $\pi^- p$ interactions at beam momenta from 700 to 2400 MeV/c. The principal reactions being analyzed are

$$\pi^- p \rightarrow n\pi^0 \quad (1)$$
$$\rightarrow n\eta \quad (2)$$
$$\rightarrow n\pi^0\pi^0. \quad (3)$$

All particles in the final state (produced in an LH_2 target 8-in. long) are detected by means of 20 neutron counters and a 4π solid-angle array of lead-plate spark chambers. The latter, which are 7 to 8 radiation lengths thick, are used to detect electron showers from γ rays. The program involved three separate experimental setups at the accelerator. The data-collection phase was completed in the spring of 1970, with a total of about 1.25 million pictures taken. At present, we are in the midst of an intensive long-range analysis of this data, which is expected to continue through FY 1972. The main goals of the analysis are: 1) to study the energy dependence of the differential cross-sections for purposes of making an S-channel partial-wave analysis; 2) to complete a high-statistics measurement of the neutral decay modes of the η meson; and 3) to study the $\pi^0\pi^0$ system in a search for scalar mesons and to measure the S-wave π-π phase shifts.

Polarization Parameter in $\pi^- p \rightarrow n\pi^0$

Using much of the same equipment as in the preceding spark-chamber experiments, but replacing the LH_2 target with a polarized target developed at LBL, we have set up an experiment at the Bevatron to measure the polarization parameter in the reaction $\pi^- p \rightarrow n\pi^0$ at various beam momenta between 1000 and 1600 MeV/c. No such measurements have as yet been made in this energy region. The equipment is all set up now on the floor of the Bevatron, and we are in the final stages of checking out the performance of the apparatus. We expect to begin taking data in the next few weeks. The experiment is being done in collaboration with members of the Segrè-Chamberlain and Kenney-Helmholz groups of LBL.

Study of $\pi^- p \rightarrow n\pi^0$, $n\eta$, and $n\pi^0\pi^0$

In collaboration with members of the Kenney-Helmholz group of LBL and scientists from Cal-Tech and NAL, we are preparing an experiment to study the above reactions at NAL. The two-body reaction cross sections are among the most important measurements to be made in the new high-energy region available at NAL. A measurement of the forward differential cross sections of the $\pi^0 n$ and ηn reactions provides the most direct experimental test of the validity of the simple Regge theory at these high energies. Secondly, the 0-deg. cross section of the charge-exchange reaction, $\pi^- p \rightarrow \pi^0 n$, is sensitive to small differences between the $\pi^- p$ and $\pi^+ p$ total cross sections,

and is thus a sensitive measure of the asymptotic behavior of these hadronic total cross sections. Finally, as an important by-product of the experiment, we will be able to measure the reaction $\pi^- p \rightarrow n\pi^0\pi^0$ to search for new I = 0 and I = 2 boson resonances.

The experiment utilizes a new scheme to accurately determine the π^0 or η directions. The detector is a counter hodoscope, composed of 140 narrow "finger counters" that locate the shower position and integrate its total energy loss. This knowledge allows one to uniquely solve for the π^0 or η direction. Tests have already been made at SLAC which verify that the detector will operate as calculated. In addition, a highly efficient veto system of counters to detect and veto a large expected background of gamma rays and charged particles has been designed, and prototypes have been successfully tested at the Stanford Mark III linear accelerator and at the University of California Davis cyclotron. Construction and final testing of all the apparatus should be completed in a few months time.

COSMIC-RAY EXPERIMENTS

High-Altitude Particle Physics and Cosmic-Ray Experimental Facility

Luis W. Alvarez and Michael A. Wahlig (LBL); Andrew Buffington, Richard A. Muller, George Smoot, and Lawrence H. Smith (Space Sciences Laboratory), University of California, Berkeley

We have been occupied during the last year with the preparation and flight of our cosmic-ray balloon experiment, data analysis of the first flight, design studies for a new cosmic-ray experimental gondola, and activities which we hope will come to fruition in a satellite cosmic-ray experiment.

Our Small Superconducting Magnet (SSCM) gondola system was successfully flown on 18 September 1970 and again on 7 May 1971 from Palestine, Texas (Fig. 1). The film from the first flight has been measured on an automatic encoding machine, and the measurements have been interpreted to yield a momentum spectrum for individual elements ranging from hydrogen to neon. When our data analysis, scanning, and calibrations are finished, we will have several thousand events of lithium and above, better statistics than any other experiment by nearly a decade. We will also have a helium spectrum with about 10^4 events and a hydrogen spectrum with 5×10^3 events. The data of the second flight will increase the statistics as well as eliminate a correction to the data due to delta rays operating the anti-coincidence scintillator.

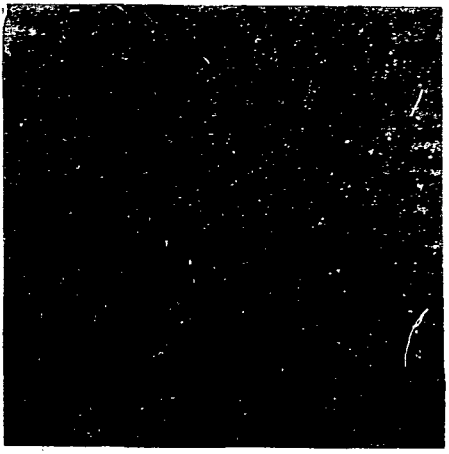

Fig. 1. Gondola is held in place until launch by Tiny Tim, the HAPPE (High Altitude Particle Physics Experiment) launch vehicle. Instruments--which included a superconducting magnetic spectrometer and an array of optical spark chambers--have recorded 60 000 spark-chamber pictures on each flight.
(XBB-717-3262)

Design is rapidly advancing on our next experiment, in which a water Cerenkov counter will be added below a magnetic spectrometer. Addition of the measurement of Cerenkov light to the momentum and charge measurements already performed by SSCM will enable

us to separate individual isotopes of the cosmic rays up through neon. Of particular interest is the isotope ^{10}Be, whose radioactive decay permits an unambiguous "dating" of the cosmic rays. Further, the ratios of source isotopes, such as carbon or oxygen, provide useful information bearing on the nuclear processes that are going on in the cosmic-ray sources.

Our proposal to NASA to measure separately the electron and positron spectra in the second High-Energy Astronomy Observatory (HEAO) Satellite has been accepted. Early studies of cryogenic design and other technical problems are now under way, although extensive funding of this project is not possible until mid-1972. The tentative launch date is mid-1976. Our apparatus will utilize a 1-year-lifetime liquid-helium dewar for our superconducting magnet. The electron or positron trajectory will be measured in a wire-chamber system close to the magnet, and the energy will be separately measured in a total-absorption counter. The resulting spectra will shed light on the propagation of cosmic rays, their interactions and leakage from the galaxy, and will give further information about the cosmic-ray sources.

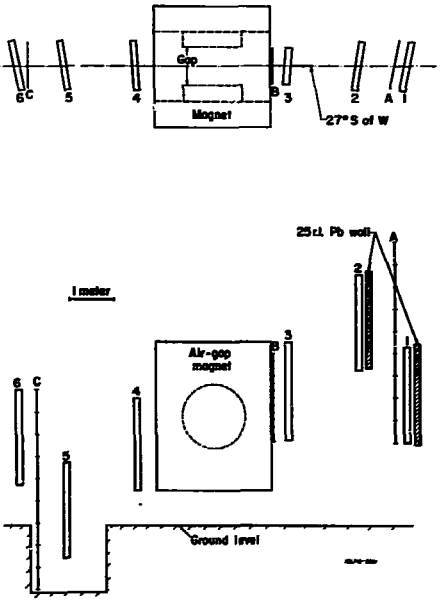

Fig. 2. Schematic of apparatus for cosmic-ray muon experiment: A, B, and C are scintillation-counter hodoscopes, M is a 30 kG-m airgap magnet, and 1 to 6 are optical spark chambers. Mirrors to give a 90 deg stereo view of each chamber are not shown, nor is the 70-mm camera which views from a distance of 20 m. (XBL-712-2961)

LBL-SLAC Cosmic-Ray Experiment

Stanley M. Flatté, Richard DeCoster, M. Lynn Stevenson (LBL); William Toner and Ted Zipf--SLAC

With the apparatus shown schematically in Fig. 2, we have gathered over 1.5 million pictures of cosmic-ray muons in spark chambers. The low-momentum cutoff is about 5 GeV/c, and the angular acceptance covers 50° to 90° zenith angle. The Geometry-Time factor for the experiment is approximately 2×10^9 cm^2-sr-sec. More than 300 events with momentum above 1000 GeV/c have been found. The muons traverse a 27 kg-m magnet, and the measurement error on the bend angle corresponds to the bend of a 2000 GeV/c particle. With these data, we see no evidence for anomalous muons[1] above 1 TeV. The results for momenta above 1 TeV were presented at the Stanford APS meeting and have been published[2] (see Fig. 3).

1. H. E. Bergeson et al., Evidence for a New Production Process for 10^{12}-eV Muons, Phys. Rev. Letters 19, 1487 (1967) and 11th Int. Conf. Cosmic Rays, Budapest, 1969, MU 31.
2. S. M. Flatté, R. J. DeCoster, and M. L. Stevenson, Zenith-Angle Distribution of Atmospheric Muons Above 1 TeV, Phys. Letters 35B, 345 (1971).

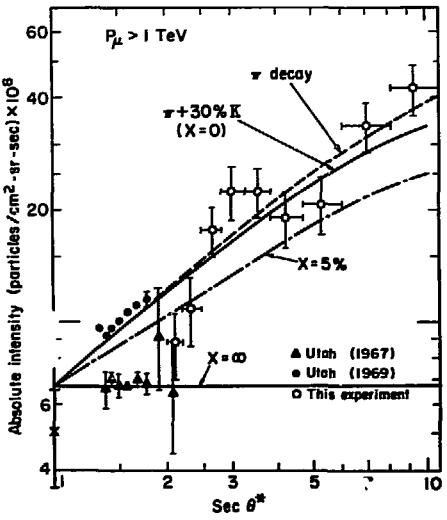

Fig. 3. Angular distribution of atmospheric muons above 1 TeV. The solid curve is the best fit to the conventional model of pion and kaon decay, using all our data above 0.3 TeV with an absolute normalization constraint from other experiments represented by the cross. Our data, the vertical point, and the curves are absolutely normalized. The Utah data are from their smallest depth (2400 hg/cm^2) and represent a slightly lower energy than our experiment. The Utah points have been slightly shifted in absolute normalization so that they can be directly compared with the theoretical curves. The parameter x measures the ratio of anomalous muons to pions at production. (XBL-712-2959)

SEARCH FOR MONOPOLES

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

A search for monopoles in Apollo XIV fines and selected samples of Apollo XI and XII material was carried out at the Manned Spacecraft Center in Houston, Texas, in April of this year. No monopoles were found in over 10 kg of lunar material. Detailed analysis of the measurements and interpretation of the results are being worked on now. A final report has been prepared concerning the Apollo XI search carried out previously.[1]

Work is progressing on a target and trap for the approved experiment to search for monopoles produced by the NAL beam. An exposure of the target is anticipated in early 1972.

1. Philippe H. Eberhard, Ronald R. Ross, Luis W. Alvarez and Robert D. Watt, Search for Magnetic Monopoles in Lunar Material, Lawrence Radiation Laboratory Report UCRL-20835, June 1971, to be published in Phys. Rev.

DETECTOR DEVELOPMENT

Detectors Using Liquified Noble Gases

Luis W. Alvarez, Stephen E. Derenzo, Gerard Smadja, Robert G. Smits and Haim Zaklad (LBL); Richard A. Muller (Space Sciences Laboratory); University of California, Berkeley

We have studied the proportionality, efficiency, and gain of a single-wire proportional chamber and the spatial resolution of a multiple-wire ionization chamber, both filled with liquid xenon. In developing these counters, we are following a suggestion by Alvarez that we might overcome some fundamental limitations of conventional spark chambers and multiwire proportional chambers--which are unable to achieve a spatial resolution much better ±200 μ--by decreasing the thickness of the chamber and increasing the density of the detecting medium.[1-3]

The geometry of our single-wire chamber is similar to that of a standard gas-filled proportional counter except that the anode wire is extremely fine, as small as 3.5μ in diameter, in order to have high gain without spurious electrical discharges. The chamber is approximately 100% efficient in detecting the alpha particles from its internal americium-241 source. Its low-voltage behavior can be understood in terms of electron avalanche with a

Measurement of the T = 3/2 Kπ Elastic Scattering Cross Section, Lawrence Radiation Laboratory Report UCRL-19426 Rev., Feb. 1971, submitted to Phys. Rev.

11. Z. Ming Ma and E. Colton, Evidence for a Narrow $N^{\mp}$(1470), Phys. Rev. Letters 26, 333 (1971).

12. C. Morehouse et al., Asymmetry in π^+ Photoproduction from a Polarized Target at 5 and 16 GeV, Phys. Rev. Letters 25, 835 (1970).

13. C. C. Morehouse, Photoproduction of π^+ Mesons from a Polarized Proton Target at 5 and 16 GeV (Thesis), Lawrence Radiation Laboratory Report UCRL-19897, Aug. 1970.

14. T. M. Powell, Search for Polarization in Elastic e^-p Scattering at 15 and 18 GeV (Thesis), Lawrence Radiation Laboratory Report UCRL-20093, Aug. 1970.

15. P. Robrish et al., Backward np Scattering with a Polarized Target, Phys. Letters 31B, 617 (1970).

16. S. Rock, Search for T-Violation in the Inelastic Scattering of Electrons from a Polarized Proton Target (Thesis), Lawrence Radiation Laboratory Report UCRL-20041, Aug. 1970.

17. D. H. Saxon, J. H. Mulvey, and W. Chinowsky, π^-p Reactions at 456, 505 and 552 MeV/c, Phys. Rev. D2, 1790 (1970).

18. H. M. Steiner, Pion-Nucleon Scattering: Experiments and Phase Shifts, Lawrence Radiation Laboratory Report UCRL-20678, Apr. 1971.

19. Clyde E. Wiegand and Richard H. Pehl, Measurement of Kaonic X Rays from ^{4}He, Lawrence Berkeley Laboratory Report LBL-22, July 1971.

20. Clyde E. Wiegand, Semiconductor Detectors in High-Energy Physics, Lawrence Radiation Laboratory Report UCRL-20042, Sept. 1970, presented at Intl. Conf. on Instrumentation for High Energy Physics, Dubna, USSR, Sept. 8-12, 1970.

If two planes of multiwire proportional chambers are used with an external absorber, we estimate that 99.0% efficiency can be achieved. We are continuing our Bevatron tests to verify this number.

1. S. E. Derenzo, D. B. Smith, R. G. Smits, H. Zaklad, L. W. Alvarez, and R. A. Muller, Recent Developments in High-Resolution Noble Liquid Detectors, Lawrence Radiation Laboratory Report UCRL-20118, Oct. 1970, and National Accelerator Laboratory Summer Study Report SS-181 (Batavia, Sept. 1970).
2. R. A. Muller, S. E. Derenzo, R. G. Smits, H. Zaklad, and L. W. Alvarez, Particle Detectors Based on Noble Liquids, Lawrence Radiation Laboratory Report UCRL-20135, Oct. 1970, and Proceedings of the Int. Conf. on Instrumentation for High Energy Physics, Dubna, 1970.
3. R. A. Muller, S. E. Derenzo, G Smadja, D. B. Smith, R. G. Smits, H. Zaklad, and L. W. Alvarez, Liquid-Filled Proportional Counter, Phys. Rev. Letters 27, 532 (1971).
4. S. Parker et al., Measurement of the Position and Energy of 4.5 GeV and 9 GeV Electron-induced Showers Using Multi-Wire Proportional Chambers, Bull. Am. Phys. Soc. 16, 658 (1971).
5. R. Jones et al., Quantameter Test Program, LRL Physics Notes, 5 January 1971.
6. S. Parker et al., University of Hawaii-LRL Quantameter Test Program, Phase II, SLAC Users' Bulletin, 3 February 1971.
7. D. Yount, Delta Rays and the Proportional Quantameter, UH-511-92-71.

PARTICLE DATA GROUP

Angela Barbaro-Galtieri, Thomas Lasinski, Alan Rittenberg, Arthur H. Rosenfeld, Thomas Trippe (LBL); LeRoy R. Price (UC Irvine)

This group is involved in three major activities:

(a) The annual issuance of "Reviews of Particle Properties," which is published alternately in Rev. Mod. Phys. and Phys. Letters.[1,2]

(b) The compilation of data on particle cross sections. These reports are printed and distributed by both CERN and LBL.[3] The two compilations now under way are $\bar{p}$ and π^+ interactions. In addition, we have started a major collaboration with Prof. Geoffrey Fox of Caltech to compile all quasi-two-body information, both on magnetic tape and in reports.

(c) The development of a computer system which will handle the storage, retrieval, and output of both data and references on particle cross sections. We are working towards the issuance of an annual literature index which will include all high-energy physics information, whether or not we have yet encoded the data; this includes approved experiments at various accelerators, preprints, conference proceedings, and of course publications.

1. M. Roos et al., Review of Particle Properties, Phys. Letters 33B, 1 (1970).
2. A. Rittenberg et al., Review of Particle Properties, Rev. Mod. Phys. 43, 81 (1971).
3. O. Benary et al., NN and $\overline{\text{NN}}$ Interactions Above 0.5 GeV/c--a Compilation, Lawrence Berkeley Laboratory Report UCRL-20000 NN, Aug. 1970.

DATA-REDUCTION OPERATIONS

Edward H. Hoedemaker

The manpower level of the Scanning and Measuring group averaged 41.4 full-time equivalents this year, a 15% decrease from the same 12-month period last year. Eighteen experiments required scanning, with three principal experiments accounting for two-thirds of the total scanning effort. Table I lists the six largest experiments. Total frames scanned was 2 381 856. The group measured 989 747 events; the relevant breakdowns are shown in Tables II and III.

Table I. Scanning distribution.

Experiment name (number)	Frames of first production scan	Frames of second and third production scans	Scan effort (h)
High-altitude			
balloon exp. (22)			
1st scan	36757		701.5
2nd scan		3279	95.4
Miscellaneous			508.6
π82 (32)			
1st scan	557922		4452.6
2nd scan		41292	367.8
Miscellaneous			5695.2
N^* Decay (35)			
1st scan	66274		771.0
2nd scan		7100	116.9
Miscellaneous			89.2
Laser (37)			
1st scan	330208		1469.5
2nd & 3rd scans		327738	1348.8
Miscellaneous			3179.3
CR69 (42)			
1st scan	265958		705.8
2nd & 3rd scans		246564	584.3
Miscellaneous			1181.2
Sirr (43)			
1st scan	175833		3451.4
2nd & 3rd scans		27006	539.3
Miscellaneous			2570.3

Table II. Breakdown of measurements by machine used.

Machine	Events	Measuring hours
Franckenstein	5445	951
Spiral Readers	792 134	12 353
SASS	192 168	2 988
Total	989 747	16292

Table III. Breakdown of measurements by experiment.

Name (number)	Description	Number of events
Bubble chamber experiments		
Purdue (15)	$\pi^- d$	18 356
π82 (32)	$\pi^+ p$, 82 in	636 970
Laser (37)	γp, 82 in	24 248
K70 (44)	$K^- p$, 25 in	80 388
K67 (46)	$K^- p$, 25 in	35 737
Miscellaneous		1 880
Total		797 579
Spark chamber experiments		
N^* decay (35)	$\pi^- p$, optic, n TOF	30 202
Nππ (43)	$\pi^- p$, optic, n TOF	161 966
Total		192 168
Total for group		989 747

PROGRAMMING EFFORT

B. Pardoe (supervisor), U. Arkadir, O. I. Dahl, N. L. Gould, M. Hoffman, M. S. Hutchinson, W. O. Koellner, M. Leavitt, E. G. Lieberman, S. W. Reynolds, E. A. Romascan, and J. J. Wilson

Bubble-Chamber Programs

The new version of the Spiral Reader filtering program (POOH), which searches for the tracks missing in a given view using information from the tracks found in the other views, has undergone further development. At present 97.5% of events are passed by POOH, and current indications are that the new version of POOH will have a pass rate approaching 99%.

Logic is also being incorpcrated into POOH to detect tracks incorrectly flagged as stopping which actually pass through the top glass of the bubble chamber.

A further reduction (by 4K words) in the field length of SIOUX, the program for reconstructing and fitting bubble-chamber events, is being effected by use of new input/output routines; and the general event-handling program MERGE-SELECT for merging tapes of data and collecting specified events from a tape, has been partly recoded with a consequent increase in execution speed of about 25%.

Spark-Chamber Programs

The SASS system was readied for the High Altitude Particle Physics Experiment, and a preliminary pass has been made through the 60 000 events recorded during the balloon flight of September 1970.

The programming work for the cosmic-ray angular-distribution experiment was completed (apart from minor modifications which may be necessary in future), and the experimental data are now being processed.

Streamer-Chamber Programs

Preparation has begun for the streamer-chamber experiment and methods are being discussed for the data reduction. A program to simulate measurements of streamer-chamber film is being developed.

General Support

The initial operating program for the computer-driven Franckenstein measuring projector (MPIIB) was completed, together with hardware check-out programs and various software maintenance programs. One of the features of the operating system is the use of track-off-center information, provided by the hardware, to determine more precise track coordinates. This permits the tracks to be measured faster as the cross-hairs do not need to be kept as closely aligned to the track as with the other Franckensteins.

Extensive changes have been made in our fitting program OPTIME, including introduction of additional estimators and stepping procedures. Currently, efforts are being directed to reducing the cost of using the program. The program is already in use at various domestic and foreign institutions.

The Crossplot program, which the Particle Data Group will use to generate graphs for their data compilation, was finished.

A program NCRPLOT, which produces plots of publishable quality on the CALCOMP and which was adapted from a program used by the Goldhaber group, was made available.

In conjunction with Nuclear Chemistry, we are developing a computerized multifont editing and type-setting system, comprised--ultimately--of CRT terminals connected to a PDP-8 which is interfaced to the CDC-6600. The PDP-8 will handle the editing and display functions; and the CDC-6600 the more complex functions of page composition, data-base manipulation, etc. The composed page will be set on a SC-4060 microfilmer.

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EXPERIMENTAL PHYSICS

Burton J. Moyer and A. Carl Helmholz in charge

This Group's research program continues to be diversified, involving experiments utilizing the Bevatron and the 184-in. cyclotron. Recently a proposal has been accepted for the first round of experiments at the National Accelerator Laboratory, and another long-range NAL proposal is in preparation. Our Bevatron research includes studies in both hadron physics and the weak interactions.

As in previous years, considerable effort has gone into instrumentation, especially spark chambers, Charpak chambers, and readout devices. Effort is presently directed toward developments of multiwire chambers and methods of readout of the resulting information. There are wide applications for these developments in high and medium-energy physics as well as in medicine.

$\pi^- p$ CHARGE EXCHANGE AT NAL ENERGIES

Robert W. Kenney, Michael Wahlig, Orin Dahl, and Morris Pripstein

In collaboration with Cal-Tech we have an investigation of the reaction $\pi^- p \to \pi^0 n$ scheduled on the first round of NAL experiments. The differential cross section at small momentum transfer [$t < 2\,(\mathrm{GeV}/c)^2$] can be measured with adequate counting rates up to 200 GeV; this information will lead to two different and exciting results:

1. The total cross section, deduced with the aid of the optical theorem, will give the most sensitive test of equality of $\pi^- p$ and $\pi^+ p$ total cross sections, thereby testing the Pomeranchuk theorem. Perhaps some of the conflicting results surrounding this point will be laid to rest.

2. Predictions of Reggeism must be put to the test. Traditionally, extrapolations to higher energy have been found somewhat wanting; new data in higher energy regions are most important for confirming and extending the Regge-based ideas.

Our proposed measurements of $d\sigma/dt$ are directly predictable, and the data will bear equally directly and immediately upon theoretical activity above 100 GeV.

At this writing, scheduling uncertainties prevail at NAL. We expect to complete our preparations in January 1972 and hope to be installed at NAL during the coming spring.

CHARGE-EXCHANGE POLARIZATION

R. Chaffee, R. Johnson, R. W. Kenney, J. Nelson, W. Oliver, D. Pollard, A. Skuja, M. Wahlig, O. Dahl, M. Pripstein, L. Anderson, A. Bridgewater, O. Chamberlain, W. Gorn, P. Robrish, S. Shannon, G. Shapiro, and H. Steiner

The elementary pion-nucleon charge-exchange reaction $\pi^- p \to \pi^0 n$ has been extensively studied in the resonance region without much attention having been given to the neutron polarization parameters. Significant contributions to phase-shift analysis are expected from this work, perhaps even a unique energy track selection from the myriad phase-shift solutions throughout the resonance region.

The experimental setup is progressing with data-taking expected to begin before the end of

1971. Eight-hundred running hours on the Bevatron are approved for this collaboration with Group A and the Segrè-Chamberlain group.

NEUTRAL DECAY MODES OF THE η^0 MESON

Roger Chaffee, Robert W. Kenney, Jerry Nelson, Andris Skuja, Orin Dahl, Morris Pripstein, and Michael A. Wahlig (LBL); Thomas B. Risser (Saclay)

The gamma-detecting spark-chamber array developed for the K_L^0 experiment is ideal for studying branching ratios among the neutral decays of the η^0 into the states $\gamma\gamma$, $\pi^0\gamma\gamma$, and $3\pi^0$. These ratios are important to theoretical understanding of the η^0 particle. Data from various experiments have given divergent results. The equipment and techniques here developed are expected to resolve this problem convincingly on the basis of data we have acquired during the past and present fiscal years.

In our experiment (done in collaboration with Group A), selection of the reaction $\pi^- p \to \eta^0 n$ is made by time-of-flight and angle determinations on the neutrons. The correct neutron counter signature triggers the chambers, thus displaying the array of showers and allowing identification of the particular neutral final-state through shower multiplicity and kinematic determinations.

Preliminary results for the branching ratios have been obtained and are reported in a Ph. D. thesis.[1] It is found that

$$R\left(\frac{\eta^0 \to \gamma\gamma}{\eta^0 \to \text{all neutrals}}\right) = 0.580 \pm 0.013$$

$$R\left(\frac{\eta^0 \to 3\pi^0}{\eta^0 \to \text{all neutrals}}\right) = 0.420 \pm 0.015.$$

Furthermore, it is found, with 95% confidence, that

$$R\left(\frac{\eta^0 \to \pi^0\gamma\gamma}{\eta^0 \to \text{all neutrals}}\right) < 0.061.$$

Reduction of these statistical errors is currently being carried forward with the other phases of our $\pi^- p$ data, and the final results will appear this year. Further investigation is under way of the $\pi\gamma\gamma$ final state. The error in the measurement of this branching ratio can be significantly reduced. The experiment has given us outstanding statistical and systematic data, and should bring to an end the uncertainty that has attended this aspect of η^0 phenomenology.

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SEARCH FOR $N^*(1680) \to \eta^0 n$

Roger Chaffee, Robert W. Kenney, Jerry Nelson, Andris Skuja, Orin Dahl, Morris Pripstein, and Michael A. Wahlig (LBL); Thomas B. Risser (Saclay)

The group-theoretical classification of the various isobar states of the nucleon system predicts the decay channels that should exist for them. For example, SU(3) predicts a cross section of 0.3 mb for an $\eta^0 n$ final state via either $D_{15}[N^*(1680)]$ or the $F_{15}[N^*(1688)]$ intermediate state. Neither decay mode has been observed previously. In collaboration with Group A, we have applied our spark-chamber system to this problem for the $\eta^0 n$ final state in the region of the $N^*(1680)$ and $N^*(1688)$ isobars. In both this and the preceding experiment, neutron counters with flight-time information provide the selected condition for triggering the spark chambers.

Clean separation of η final states has been achieved, and only a few minor problems remain in the data-analysis system. The separation of N^* intermediate states has awaited the completion of software needed in the automatic measuring. Results are forthcoming at this time and will appear shortly.

$\pi^0\pi^0$ INTERACTION

Rober Chaffee, Robert W. Kenney, Jerry Nelson, Andris Skuja, Orin Dahl, Morris Pripstein, and Michael A. Wahlig (LBL); Thomas B. Risser (Saclay)

In collaboration with Group A, the reaction $\pi^- p \rightarrow \pi^0\pi^0 n$ has been extensively observed, over a range of incident π^- energies; and kinematical analyses of the $\pi^0\pi^0$ system (which must be T = 0, or in very small amount T = 2) are progressing. Preliminary results from these analyses indicate that they may yield clear evidence bearing upon the presence or absence of an "ϵ" meson, with T = 0 and J = 0, decaying into $\pi^0\pi^0$.[1] Results of this experiment will be available early in 1972.

This experiment also includes data for the process $\pi^- p \rightarrow \pi^0 n$, allowing a precise measurement of the charge-exchange differential cross section. About 10 000 events of this type have been obtained at each of five momenta of the incident π^- (1.6, 1.8, 2.0, 2.2, and 2.4 GeV/c). This is an order of magnitude more events than previously have been obtained in this energy range. The data will also allow a search for the process $\pi' \rightarrow \gamma\gamma$.

[1] M. Pripstein, New Experimental Results on the T = 0, J = 0 $\pi\pi$ System Below 1 GeV, Bull. Am. Phys. Soc. 15, 766 (1970).

OPTICAL PULSARS

Jerry Nelson (LBL); Richard Hills (Astronomy Dept., U. C. Berkeley); David Cudaback (Radioastronomy Laboratory, U. C. Berkeley); Joseph Wampler (Lick Observatory, U. C. Santa Cruz)

In order to determine the time-dependence of the frequency of a pulsar, we have devised and set into operation a method of relating the optical pulses from the pulsar to a rubidium atomic clock, which is in turn regularly standardized against the secondary time standards at the Hewlett-Packard Corporation. Observations on the Crab Nebula pulsar were made at Lick Observatory from December 1969 through May 1970, and again beginning in August 1970. To increase our data-taking rate, the observing has been transferred from the 36-in. telescope to the 24-in. telescope where we now observe full-time.

Extremely accurate determinations of the parameters used to describe the average slowdown of the pulsar have been obtained. Simple theoretical models make definite predictions about some of these parameters, but the experimental results are in disagreement with these. In addition to the smooth slowdown expected, a number of sudden changes in the pulsar parameters have been observed indicating both sudden speedups and slowdowns for the pulsar. The idea of "starquakes" has been introduced to explain these phenomena. The measurements also give detailed information on the pulse shape and its constancy.[1-2]

We should soon have enough data to check some predictions of general relativity, in particular the effect of the sun's gravitational field on clocks as the earth orbits around the sun. We should also be able to make strong statements about the properties of the so-called "starquakes" which occur occasionally in the pulsar, causing it to change frequency.

Under development is a system using multi-megapoint Fourier transforms to systematically hunt for other optical pulsars. This system should be operational this year.

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μ^--CAPTURE NUCLEAR GAMMA RAYS

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

A program is in progress at the 184-in. cyclotron to study the nuclear energy-level excitations produced by μ^--capture in complex nuclei. In addition to providing information on the nuclear interaction, this mechanism provides a rich source of primary nuclear excitations of the hole and particle-hole type and should aid in the identification of such states. Short-lived levels are uniquely distinguishable because of the Doppler broadening due to the motion of the nucleus recoiling after the capture interaction.

Data reduction of the γ-ray spectra from several nuclei following μ^--capture is proceeding. High-energy Doppler-broadened lines similar to those in O are seen in Ca and Si.[1] These are the same lines, or isotopic analogs of the lines, observed following photoexcitation or inelastic electron scattering in the giant-dipole energy region. Single-neutron emission is the dominant mode of decay; however there is also direct evidence for no-neutron, proton, and neutron-plus-proton emission. Data for natural Al, Co, and Ni targets are also being studied.

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

B. Gauld, V. Perez-Mendez (LBL); R. Cence, F. Harris, B. Jones, R. Morgado, M. Peters, L. Shiraiski, D. Yount (University of Hawaii); D. Clarke, D. Cline, R. Frommer (University of Wisconsin)

Data-taking was completed in June 1970; there now exist 1.2 million events on tape, background included. Trigger topologies are those for

$K^+ \to \pi^+\pi^-e^+\nu$ (0.6 million)
$K^+ \to \pi^+\pi^+e^-\nu$ (0.2 million)
$K^+ \to \pi^+e^+e^-$ (0.3 million)
$K^+ \to \pi^+\pi^+\pi^-$ (0.1 million).

The $K^+ \to \pi^+\pi^-e^+\nu$ process has been observed unambiguously, and very preliminary estimates indicate that a few thousand events are contained in the full body of data. It is expected that the rare mode $K^+ \to \pi^+e^+e^-$ will yield about 10 examples, twice the extant bubble-chamber data. Large quantities of τ decays ($K^+ \to \pi^+\pi^+\pi^-$) are seen and are utilized for calibration of the system. Most of the recent effort has been on program development, particularly on the difficult pattern-recognition program which "scans" our data tapes and matches sparks into tracks numerically. Analyses of some of the τ data is encouraging. Also, some 9% of the triggers for $K_{\pi ee}$ have been run through preliminary versions of the programs. Much has been learned about backgrounds and efficiencies. Analysis of the K_{e4} data is now proceeding at the University of Hawaii, while the $K_{\pi ee}$ data will be shipped to Wisconsin in the near future after considerable work on the LBL computers.

NEUTRAL DECAY MODES OF THE K_L^0

I. Linscott (LBL); W. P. Oliver (University of Washington); C. Rey (University of Notre Dame); V. Z. Peterson, S. Parker, R. J. Cence, V. Stenger (University of Hawaii)

In collaboration with the University of Hawaii, we have completed measurement of the ratio

$$|\eta_{00}|^2 = \frac{K_L^0 \to 2\pi^0}{K_S^0 \to 2\pi^0}$$

The first published result[1]

$$|\eta_{+-}|^2 = (14.1 \pm 3.4) \times 10^{-6}$$

has not changed significantly as a result of this year's application of modified kinematic tests and additional calibration data to improve the signal-to-background ratio. This work has enabled us to reduce the systematic uncertainties contributing over half of the error given above, and to establish an upper limit on the branching ratio for the decay $K_L^0 \rightarrow \pi^0 + \gamma + \gamma$.

Our result is evidence against the "superweak interaction" theory which predicts a value of 4×10^{-6} for $|\eta_{00}|^2$. Among the independent efforts at other laboratories to measure this ratio, several experiments have given results in agreement (within their errors) with "superweak." Others have been compatible with our value.

Ten thousand events $K_L^0 \rightarrow 3\pi^0$ also resulted from this experiment. They have been analyzed, via the newly developed SASS automatic scanning-pattern recognition system, to provide information on the Dalitz plot. Some structure appears to be present. Final results will soon be prepared for a Ph. D. thesis.

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ELECTROMAGNETIC DELAY LINE READOUT FOR PROPORTIONAL WIRE CHAMBERS

R. Grove, L. Kaufman, V. Perez-Mendez, J. Sperinde, K. Lee, B. Leskovar

We have developed electromagnetic delay lines to read out the position of ionizing events in multiwire proportional chambers. The delay line is rectangular in cross section and consists of a ground conductor of copper strips insulated by 0.001 Mylar from the outer conductor which is a helix of insulated copper wire. The phase dispersion inherent in delay lines of this type is compensated by the use of the floating capacitive path technique. We have built delay lines of this type with delays ranging from 5 to 30 nsec per mm, and lengths up to 55 cm. The delay line is capacitively coupled to the wire chamber by clamping it on to the wire leads on the outside of the chamber. By timing the arrival of the pulse at the end of the line, its position can be determined electronically to 0.1 mm. Measurements done on wire chambers with low-energy γ sources indicate that the delay line can interpolate the current signals from a group of wires and record position accuracies of ± 0.15 mm (1/6 the wire spacing) from the wire plane which collects the signal induced by the positive ions.

We have switched over to using multiwire proportional chambers for imaging x-ray, γ-ray, and neutron distributions. This work, a collaboration with the University of California Medical School in San Francisco, was started previously using wire spark chambers with a magnetostrictive readout. Since the proportional chambers do not need trigger signals from external scintillators, and can thus record the spatial distributions of low-energy (< 50 KeV) x-ray distributions as well, we have reoriented this project to using the proportional chambers with the electromagnetic delay line readout. For low-energy x-ray and γ-ray imaging we have used xenon-filled chambers; for high-energy γ rays, we have used argon-isobutane-filled chambers with an external lead multihole collimator, and a lead-plate converter. For use as a positron imaging camera (by detecting the two 0.51-MeV γ rays), we have used a system of two chambers without collimators. In our initial work on neutron radiography (in which K. Valentine

and S. Kaplan are participating), we are using the (η,α) reaction from a boron-coated plate to image the thermal and epithermal neutron distributions.

We have done further measurements on locating the spatial distribution of γ rays emitted from stopping π^- beams in tissue-simulating plastic. This technique will be useful in locating the combined Bragg-"star formation" peak of π^- beams, which will be used in cancer therapy at Los Alamos and elsewhere. We are doing a similar experiment on the α-particle beam from the 184-in. cyclotron in order to locate the Bragg peak of the α particles.

We are continuing to investigate and perform measurements on the use of cadmium sulphate microcrystalline layers for use in solid-state dielectric positron-locating devices. So far the layers that we have tested have been unsatisfactory, and we will investigate further compounds.

np → γd: TEST OF TIME REVERSAL

S. Wilson, M. Longo, K. Young (U. Michigan); R. Haddock, J. Helland, B. Schrock (UCLA); D. Cheng, V. Perez-Mendez (LBL)

The angular distribution of the reaction $n + p \rightarrow \gamma + d$ was measured at the 184-in. cyclotron at incident neutron energies spanning the $N^*(1238)$ resonance for the purpose of comparing this distribution to that of the inverse reaction $\gamma + d \rightarrow n + p$. Such a comparison is a direct test of time-reversal invariance, presumably in the electromagnetic interaction.

All the data were divided into neutron energy bins 100-MeV wide, centered at 350, 450, 550, and 650 MeV. A preliminary comparison with the inverse reaction showed good agreement for the 350- and 650-MeV bins and only a small disagreement for the remaining two, which reached a value of one standard deviation for the 550-MeV bin.[1] In the final analysis, no evidence for a time-reveral violation was observed.

In this experiment we also measured the angular distribution of the reaction $n+p \rightarrow \pi^0+d$ as a test of I-spin invariance in strong interactions.[2]

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2. S. Wilson et al., Isospin Invariance in the Reaction $n+p \rightarrow \pi^0+d$, Phys. Letters 35B, 83 (1971).

p + d ⇄ γ + ^{3}He: TEST OF TIME REVERSAL

M. Goltein, A. Stetz, V. Perez-Mendez (LBL); C. Heusch (UCSC); R. Klein (Cal-Tech); J. Carroll, B. McDonald (William and Mary College, Virginia)

This experiment, which ran this year at the 184-in. cyclotron, was designed to test time-reversal in electromagnetic interaction in I-spin transitions other than those available in the $np \rightleftarrows \gamma d$ experiment. The inverse reaction was done at the Cal Tech synchrotron by Heusch et al. (University of California, Santa Cruz). The ^{3}He direction and energy are obtained from a wire-chamber array and a 6-in.-thick plastic scintillator in which the ^{3}He particles stop. This counter has been calibrated over its entire area in order to determine the energy of the stopping ^{3}He ions from the measured pulse height. Two lead-glass Cerenkov counters are used to detect the position and approximate energy of the photons. Each of these counters consists of a 2-in.-thick lead-glass slab followed by 4 wire chambers, a thin scintillator, and a 20-in.-thick lead-glass block. The position of the photon is determined by the charged particle fraction that traverses the wire chambers. The energy

is determined by measurement of the light output of the slab and block combined. Data are now being analyzed.

π^0 FORM FACTOR EXPERIMENT

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

In this experiment we are determining the electromagnetic form factor of the π^0 by a measurement of the correlations of the e^+, e^- pairs obtained in the Dalitz decay of the π^0: $\pi^0 \rightarrow e^+ + e^- + \gamma$. Since completion of the cyclotron run in November 1969, we have been working on the event reconstruction and momentum analysis software. We expect a 0.2% momentum resolution from our spectrometer data and expect to extract 10^4 wide-angle events--which contribute to the form-factor determination--from our log of 10^6 triggers.

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EXPERIMENTAL PHYSICS

Edward J. Lofgren in charge

The group is involved principally in high-energy particle physics research using counter and spark-chamber techniques. Most experiments have been performed at the Bevatron; however, some work has been done in the past using the 184-in. cyclotron, and in the future we expect also to make use of NAL.

Our physics interest ranges from strong interactions--concerning nucleon-nucleon cross sections and diboson production--to measurements of branching ratios for K-meson decay modes as tests of weak-interaction hypotheses. Each experiment undertaken by the group involves one or more graduate students and forms the basis for a thesis project.

Group activities also involve instrumentation development in electronics, optical and wire spark chambers, spark gaps, Cerenkov counters, and on-line computer facilities as needed for the experimental program. There are current projects on Bevatron development and the improvement of its experimental facilities.

Researchers taking part in this work are: Alan R. Clark, R. Clive Field, Henry J. Frisch, William R. Holley, Rolland P. Johnson, Leroy T. Kerth, John F. McReynolds, Richard P. Sah, Gilbert Shen, W. A. Wenzel, and Arthur M. Zingher--LBL; Bruce Cork--Argonne National Laboratory; Tom Elioff--on leave from LBL to USAEC, Washington, D. C.; T. N. Rangaswamy--Tata Institute of Fundamental Research, Colaba, Bombay, India; and David Newton--University of Lancaster, England.

DIBOSON PRODUCTION

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

The dominant feature of the dipion mass spectrum is the ρ-meson. In addition, we see evidence for the decay $\omega \to \pi^+ \pi^-$ for t-values somewhat above the kinematic lower limit. At our higher incident momenta, there is also evidence for an enhancement at a mass of ~ 936 MeV, with a width of ~ 50 MeV. Analysis of the data is continuing, with our recent efforts directed toward improvements in the geometrical efficiency calculations. We also have data on the reaction $\pi^- p \to K^+ K^- n$; these data will be analyzed after completion of the dipion analysis.

$(K^+ \to e^+ \nu)/(K^+ \to \mu^+ \nu)$ BRANCHING RATIO

The Bevatron experimental run was completed in June 1968. About 250 000 photographs were taken, 90% with the analyzing magnet set for $K^+ \to e^+ \nu$. Analysis of the data has been completed, yielding 140 ± 15 events after a background subtraction. This is to be compared with the previous world's total of 17.0

±7.5. We have obtained the result

$$\frac{\Gamma(K \to e\nu)}{\Gamma(K \to \mu\nu)} = 2.42 \pm 0.36 \times 10^{-5},$$

which is in agreement with the V-A prediction (including radiation corrections) of 2.22×10^{-5}.

LIMITS ON $K_L^0 \to \mu^+\mu^-$, e^+e^-, $e^\pm\mu^\mp$

We have used a double-arm spark-chamber spectrometer to search for the decays $K_L^0 \to \mu^+\mu^-$, e^+e^-, or $e^\pm\mu^\mp$. The spectrometer has invariant mass resolution of better than 1/3%.

Eighty-five percent of the data was accumulated with the kaons decaying in vacuum. No candidates for any of the dileptonic decay modes were detected. The 90% C. L. limit from these data is

$$\frac{\Gamma(K_L^0 \to \ell^+\ell^-)}{\Gamma(K_L^0 \to \text{all})} \leq 1.82 \times 10^{-9}$$

for each of the above modes. These limits represent reductions from the previous limits by factors of 14, 95, and 2300, respectively, for the $\mu\mu$, ee, and $e\mu$ modes.

The remaining 15% of the data was accumulated with the kaons decaying in helium. A significant background due to neutron interactions with the helium was present for the decays $K_L^0 \to \mu^+\mu^-$. Candidates for the decay $K_L^0 \to \mu^+\mu^-$ were detected with probabilities estimated at 65%, 25%, 3%, 0.02%, <0.01%, and < 0.001%. All but the 65%-probable event and possibly the 25%-probable event are clearly neutron-induced background. These two events are compatible with either the neutron-background hypothesis or the $K_L^0 \to \mu^+\mu^-$ hypothesis. If these events were to be regarded as background and the helium data rejected, the 90% C. L. limit on $K_L^0 \to \mu^+\mu^-$ resulting from this experiment is that quoted above for the vacuum data. If one regards the helium data as valid and the 65%-probable event as a $K_L^0 \to \mu^+\mu^-$ decay, the resulting branching ratio is

$$\frac{\Gamma(K_L^0 \to \mu^+\mu^-)}{\Gamma(K_L^0 \to \text{all})} = 6.8 \times 10^{-10}$$

with a statistical error based on one event.

Either of these two numbers is in drastic conflict with the expected electromagnetically induced $K_L^0 \to \mu^+\mu^-$ rate. Both numbers are also in conflict with the lower "unitarity" limit of 6×10^{-9} calculated from the known $K_L^0 \to \gamma\gamma$ rate.[1] Because of the general nature of this unitarity limit, this result is quite unexpected.

The 90% C. L. limit from the combined vacuum and helium data on each of the three modes $K_L^0 \to e^+e^-$, $e^+\mu^-$, and $e^-\mu^+$ is 1.6×10^{-9}. For these modes there is no conflict with theoretical predictions.

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STUDIES OF $K_L^0 \to \pi\ell\nu$ DECAYS

$K_L^0 \to \pi\ell\nu$ events which were accumulated during the $K_L^0 \to \ell^+\ell^-$ search are now being analyzed. A preliminary study has indicated that muon neutrino mass limits will be possible that are lower by a factor of three or more than those presently achieved.

Other $K_L^0 \to \pi\ell\nu$ data, which were taken with the neutral-currents apparatus but with different spark-chamber trigger criteria, have yielded useful information. A search for a reported $\pi^\pm\mu^\mp$ resonance near 427 MeV/c^2 was made. Better resolution and a data sample over 150 times as large as that of the experiment reporting the resonance gave strong evidence that the resonance did not exist.

Dalitz-plot analyses of the above data sample are now being made for the $K_L^0 \to \pi\ell\nu$ events. Studies involving the tensor component, the vector form factors (q^2) and λ, and radiative corrections are under way. Useful information on each of these seems very likely.

SEARCH FOR LONG-LIVED NEUTRALS

Possible evidence for the existence of long-lived neutral particles which decay into electron-positron pairs was reported recently at Cambridge.[1] We have conducted a search for these particles in a neutral-particle beam originating from a copper target placed in an external proton beam of the Bevatron. If such particles were produced and if their lifetimes were long enough (10^{-4} to 10^{-10} sec) for such particles to reach the decay volume, then the electron-positron pairs arising from their decays would be detected by the double spectrometer, which was constructed for the search for neutral leptonic currents.

Data taken for approximately one hundred hours at the end of July 1970 have been analyzed, and no mass peak indicating the existence of such neutral particles was observed. Upper limits on the differential production cross section for such particles have been determined for each of three assumed lifetimes. Production cross sections are less than 10^{-35} $cm^2/MeV \cdot Sr$ in the invariant-mass range 30 to 50 MeV/c^2 and for an assumed lifetime of 10^{-8} sec.

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$K^0\mu3$ AND K^0e3 CHARGE ASYMMETRY

Data are being taken to measure the charge asymmetries of the decay modes $K_L^0 \to \pi\nu$. The double spectrometer, which was constructed for the search for neutral leptonic currents, is being used. Modifications were made to the trigger system during the first few days of April 1971, and data-taking began immediately afterward.

The new trigger system requires the pion to penetrate only one scintillator on one side of the apparatus, and the lepton to count on the other side in the scintillator and also in either the range detector or the Cerenkov counter. The low-mass spark chamber system is used to analyze each event completely.

As estimated 6 million $K\mu3$ events and $Ke3$ events have been recorded.

$K^0\mu3$ POLARIZATION MEASUREMENT

This experiment will examine the variation of the muon polarization direction in $K^0\mu3$ decays as a function of the kinematic configuration of the decay. It is intended to measure the variation of the real and imaginary parts of the form factor, on which the polarization is principally dependent, and possibly by this means illuminate the source of discrepancy in previous measurements of ξ.

The modifications to the equipment used previously for the $K_L^0 \to \mu^+\mu^-$ experiment continued through June. The principal effort has been the design of a large volume muon polarimeter consisting of an aluminum-scintillator sandwich in a magnetic field. The polarimeter will have a useful volume of 48X48X 56 in. and will use a ~ 100 G magnetic field uniform to ~ 0.1 G. It will examine about 60% of the spectrum of the muons. The electronic recording equipment associated with the polarimeter is completed and will be ready and tested before the polarimeter is assembled.

We expect to complete the setup and begin taking data during September 1971.

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EXPERIMENTAL PHYSICS

Wilson M. Powell and Robert W. Birge in charge

The Powell-Birge group works in the field of high-energy particle physics using hydrogen bubble chambers. The main emphasis has been the detailed study of interaction mechanisms both in the low-energy (1 to 2 BeV) resonance region and the intermediate-energy (2 to 4 BeV) peripheral region.

The low-energy region is expected to be dominated by s-channel resonances; in particular, the $\Delta(1950)$ is contained in this energy range and a study of the energy dependence of the various final states should give information about the inelastic partial widths of this resonance. At the higher energies, resonance production is thought to be dominated by the exchange of Regge-poles; we are testing these ideas in $\pi^+ p$ interactions. In support of these activities, automatic scanning and measuring machines and associated computer programs are used to analyse several hundred thousand events each year.

$K^- p$ INTERACTIONS: 0.85 TO 1.70 GeV/c

R. W. Birge, R. P. Ely, G. E. Kalmus, D. F. Kane, and A. J. Van Horn

We have obtained data for the reactions $K^- p \to \Sigma^{\pm}\pi^{\mp}(\pi^0)$, $K^- p \to \Lambda\pi^0$, and $K^- p \to K^0 n$ for laboratory momenta between 0.82 and 1.70 GeV/c: angular distributions, polarizations, and Legendre coefficients for the two-body final states; Dalitz plots and invariant mass squared plots for $\Sigma^{\pm}\pi^{\mp}\pi^0$; and cross sections for all these reactions. We have also performed partial-wave analyses based on the $\Sigma\pi$ and $\Lambda\pi$ final states; preliminary results were reported at the XVth International Conference on High Energy Physics at Kiev.[1,2]

The analysis of the $\Sigma^{\pm}\pi^{\mp}$ final states has been completed.[3,4] We confirm the presence of resonant structures in the F15 and D13 waves. The masses, widths, and resonant amplitudes were determined: $E_R = 1.925 \pm 0.008$ GeV, $t = -0.137 \pm 0.015$, and $\Gamma = 0.146 \pm 0.022$ GeV for the F15; $E_R = 1.985 \pm 0.005$ GeV, $t = -0.093 \pm 0.006$, $\Gamma = 0.208 \pm 0.022$ GeV for the D13. We studied the D5 and F5 octets, F7 decuplet, and G7 singlet for SU_3 symmetry of reduced coupling constants; possible conclusions are limited by uncertainty about the detailed energy dependence of the couplings. These results have been submitted to Physical Review, along with the experimental data.

The analysis of the $\Lambda\pi$ final state is not yet complete. However, the data from both the $\Lambda\pi^0$ and $K^0 n$ final states will be submitted for publication shortly.

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π^+p INTERACTIONS: 2.1 TO 2.7 GeV/c

George Gidal, Donald Grether, Winston Ko, and William Michael

In a continuing study of exchange mechanisms producing quasi-two-body final states, we have completed the following projects:

$\pi^+p \to \rho^+p$

A detailed analysis[1] was made of the reaction $\pi^+p \to \rho^+p$ at 2.67 GeV/c using a sample of 8300 events in the final state $\pi^+p\pi^0$. Together with published data at 2.77 GeV/c for the reactions $\pi^-p \to \rho^-p$ and $\pi^-p \to \rho^0n$, we have used this analysis to isolate the I = 0, ω^0 exchange contribution to these reactions. This amplitude is found to have a dip at $t = -0.40 \pm 0.05$ characteristic of the nonsense wrong signature zero of the ω^0 Regge trajectory.

$\pi^+p \to \eta^0\Delta^{++}$

We have measured[2] the total and differential cross sections and the Δ^{++} decay angular distributions for the reaction $\pi^+p \to \eta^0\Delta^{++}$ at incident momenta between 1.3 and 2.7 GeV/c. The 95 000 four-prong events used were measured on the FSD and COBWEB systems. The data above 2 GeV/c, when combined with some existing data, give evidence for a dip in the t distribution near $t = -1.5$ (GeV/c)^2. This dip, and other features of the data, are adequately described by the A_2 Regge pole model of Kramer and Maor. The effective A_2 trajectory was calculated and found to disagree with that obtained from the reaction $\pi^-p \to \pi^0n$.

A detailed Regge amplitude fit has been completed for the $\pi^+p \to \eta^0\Delta^{++}$ using data between 2.3 and 8 GeV/c. This reaction is pure A_2 exchange; and the best-fit trajectory function is found to be $\alpha(t) = 0.52 + 1.0t$, providing confirming evidence for ρ-A_2 exchange degeneracy. A partial-wave analysis of these amplitudes is in excellent agreement with our data for this reaction down to threshold, indicating the absence of important s-channel contributions.

$\pi^+p \to \omega^0\Delta^{++}$

Measurements have been completed[3] on the total and differential cross sections, and Δ^{++} and ω^0 decay angular distributions for the reaction $\pi^+p \to \omega^0\Delta^{++}$ at incident momenta 2.3 and 2.67 GeV/c. A separation of the unnatural parity contribution (B exchange) is performed, showing a dip structure near $t = -0.2$. The effective B trajectory from all available data is $\alpha_B = (0.15 \pm 0.12) + (0.62 \pm 0.23)t$ in agreement with the hypothesis that the dip is the nonsense wrong signature point of this trajectory. Alternative hypotheses have been proposed, but the current world data are unable to discriminate among them.

B Meson

A spin-parity analysis of the B meson produced in π^-p reactions has been performed[4] in collaboration with groups from Torino, Nijmegen and Bonn. The most satisfactory assignment is 1^+ in agreement with previous measurements. The ratio $|D|/|S| = 0.4 \pm 0.2$.

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π^+p INTERACTIONS: 1.1 TO 2.0 GeV/c

George Kalmus, Philip Hanson, William Michael

Additional 2-prong data of π^+p at 1.15, 1.20, 1.62, and 1.95 are in the process of being scanned and measured using the DAPR automatic scanning-measuring system.

Analysis of the $\pi^+p\pi^0$ channel has been carried out at six momenta below 2 GeV/c, in collaboration with a group at U. C. Riverside.

The production angular distribution for $\pi^+p \to \Delta^{++}\pi^0$ has been determined and gives evidence that s-channel resonances are strongly coupled to $\Delta\pi$ in this energy region. At the same time it is observed that dips at $t = -0.5$ and $t = t_{max}$, characteristic of ρ exchange with dominant helicity-flip coupling, are present at all momenta, providing a test of duality.

Total and differential cross-section data have been presented for π^+p elastic scattering at eight incident π^+ momenta: 1.28, 1.34, 1.40, 1.43, 1.55, 1.68, 1.77, and 1.84 GeV/c.[1] These data were obtained from a hydrogen bubble chamber exposure at the Bevatron and contain more than 65 000 events. This represents more than one and one-half times the world's data hitherto available in this energy region.

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1. G. E. Kalmus, W. Michael, R. W. Birge, S. Y. Fung, and A. Kernan, π^+p Elastic Scattering Data Between 1820 and 2090 cm Energy. Lawrence Radiation Laboratory Report UCRL-19775, July 1970.

DIFFRACTION DISASSOCIATION OF PROTONS

Robert P. Ely, Donald Grether, and William Michael

In collaboration with the California Institute of Technology we have performed a hybrid bubble chamber-spark chamber experiment at SLAC to obtain an enriched sample of events to study the diffraction disassociation of the proton. The SLAC 40-in. hydrogen bubble chamber was exposed to a beam of 14-GeV π^- mesons and triggered by a spark-chamber spectrometer which immediately followed the bubble chamber.

Outgoing negative tracks were analyzed by the spark chambers and a Sigma-2 computer with 1/2% momentum resolution, and pictures were taken of events with $0.07 \text{ GeV} < (P_{BEAM} - P_{OUT}) < 4 \text{ GeV}$. (One has 3 milliseconds between the passage of the beam and the flashing of the bubble-chamber lights to make this decision.)

We took 300 000 pictures in April and May and will take 200 000 more in July. Initial steps have been taken to measure one-half of this film on the Berkeley FSD using the DAPR automatic scanning mode. The remainder will be measured by a POLLY device under construction at C.I.T. In the meantime, preliminary investigations are being pursued with the COBWEB system.

CLOUD-CHAMBER QUARK QUEST

Wilson M. Powell

More than 100 000 cosmic-ray tracks from extensive air showers were scanned in pictures of cloud chambers after the manner of McCusker. In addition, positive- and negative-ion columns were separated by an electric field, and individual droplets were counted; histograms of numbers of tracks versus droplet density are shown. Artificially produced low-droplet-count tracks have been used to measure the scanning efficiency for quarklike tracks. To date, the upper limit for the $\frac{2}{3}e$ quark flux is 3×10^{-11} cm^{-2}sec^{-1}sr^{-1}, and the limit for $\frac{4}{3}e$ particles is 3×10^{-10} cm^{-2} sec^{-1} sr^{-1}.

DATA REDUCTION

C. Scales and D. Crocker

With an average of 13 (full-time equivalent) visual measurement personnel, the following data reduction was accomplished during fiscal year 1970-1971.

SCANNING

Experiment	Beam	Number of frames: COBWEB system	Number of frames: FSD system
45-47, 58*	1.25- to 1.85-GeV/c π^+	312 182	127 874
50-52*	1.1- to 1.6-GeV/c K^-	321 587	---
53-55, 59*	2.3- to 2.7-GeV/c π^+	1 784 184	136 533
60-64*	1.2- to 2.1-GeV/c π^+	---	568 701
66**	5.5 GeV/c D_2	1 724	---
67-68***	14 GeV/c π^-	20 265	75
	Subtotal	2 439 942	851 183
	Total		3 291 125

* 25-inch hydrogen bubble chamber
** 82-inch hydrogen bubble chamber
*** 40-inch hydrogen bubble chamber

MEASURING

	Measuring hours	Number of events	Events per measuring hour
COBWEB system	2 718	55 969	21.0
FSD system (Six SPSB-type image plane digitizers)			
HAZE mode	0	0	0
DAPR mode	1 533	139 913	91.3

γd INTERACTIONS AT 5.5 GeV/c

R. W. Birge, G. Gidal, and D. Kane

In a collaboration with the University of California at Riverside, we have taken 260 000 pictures of the 82-inch deuterium bubble chamber exposed to the 5.5 GeV/c polarized, laser-induced, photon beam at SLAC. This represents approximately half the approved exposure. Scanning is almost complete, and measurements have been started on the COBWEB system. All interactions producing strongly interacting particles will be systematically studied.

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EXPERIMENTAL PHYSICS , GROUP R

Kenneth M. Crowe in charge

RADIATIVE CAPTURE EXPERIMENTS

James A. Bistirlich and Kenneth M. Crowe (LBL); Jerome A. Helland (Los Alamos Scientific Laboratory); Peter Truoel (Physik-Institute der Universität, Zurich)

Our major effort on the 184-in. cyclotron is a study of radiative pion capture in light nuclei. During previous years, preliminary work on the π capture gamma-ray spectra was done for a series of nuclei: ^{4}He, ^{12}C, ^{16}O, ^{24}Mg, and ^{40}Ca. The technique consisted of using a large pair spectrometer with optical spark chambers. By manual scanning of the events from film, we were able to accumulate 10^3 to 10^4 events per element with a resolution of 2 MeV at 130 MeV. For the first time, we were able to show that the spectrum has fine structure, which is caused by the final-state interaction in the remaining nuclei. The results for helium and carbon have already been published;[1,2] those for oxygen, magnesium and calcium have been submitted for publication. These results are summarized by the abstracts of the papers as follows.

Helium-4 Spectrum

The spectrum of high-energy gamma rays following the absorption of negative pions in ^{4}He has been investigated. The observed shape of the spectrum and the measured total capture rate [$(0.704 \pm 0.066) \times 10^{15}$ sec^{-1}] agree well with theoretical predictions, assuming that the pions proceed through excitation of states in ^{4}H with $J^{\pi} = 2^{-}$ at 3.4 MeV, $J^{\pi} = 1^{-}$ at 5.1 MeV, and $J^{\pi} = 1^{-}$ at 7.4 MeV relative to the ^{3}H+n threshold, and taking an operator $\simeq \tau^{(-)}\sigma e^{i\vec{k}\cdot\vec{r}}$ for the calculation of the nuclear-matrix elements.

Carbon-12 Spectrum

The spectrum of high-energy gamma rays following the capture of negative pions in ^{12}C was measured with high resolution. The observed structure in the giant-resonance region is the first direct experimental proof of the influence of collective excitations in radiative pion capture. This supports recent theories concerning the analogy between this process and muon capture.

Spectra for ^{4}He, ^{12}C, ^{16}O, ^{24}Mg, and ^{40}Ca

The photon spectra following capture of stopped pions in ^{4}He, ^{12}C, ^{16}O, ^{24}Mg, and ^{40}Ca have been measured for photon energies between 50 and 160 MeV. A pair spectrometer was used and resolution of 2.0 MeV FWHM was achieved. On the basis of several thousand events for each spectrum, we observe collective excitation in the residual nucleus for capture on ^{4}He, ^{12}C, and ^{16}O. Such excitation is predicted theoretically, and in some cases detailed comparison with the data is good. For ^{24}Mg and ^{40}Ca no significant structure is seen. In addition, the transition rates to particle-stable states in ^{16}O and ^{12}C have been measured. A continuum background consistent with a direct reaction mechanism is also observed for all the elements studied except for ^{4}He.

These results were sufficient to indicate that the pion-capture radiation can be used as a probe for the study of collective modes, i. e., the giant-resonance states in carbon and oxygen, as well as to provide a way for investigating nuclear excited states. Since the visual scanning of the events was not adapted for extension to more detailed spectra, we have developed a digitized-electronic-readout wire chamber to replace the optical chambers. At the same time, a neutron-counter array was added to provide an observation of the angular correlation and energy distribution for the neutrons produced in coincidence with the gamma ray in each part of the spectrum.

This apparatus, which was installed in November 1970, has been calibrated using events from liquid hydrogen. We plan to measure the deuterium spectrum to improve the n-n scattering length. Helium-3 will be used to check the excited states of the three nucleon system n-n-p, which should show up the three-nucleon state reported by Sperinde et al.[3] from the study of $\pi^- {}^3He \rightarrow \pi^+ 3n$ reaction. A direct exploration of the three-neutron state can be made using π^- on tritium. This experiment has been considered, and a proposal to carry out the experiment at Los Alamos has been approved.

Further extensions of these studies on ^6Li leading to $^6He^*$ and a further systematic study of light nuclei is planned in the near future at the 184-in. cyclotron.

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MUON DEPOLARIZATION STUDIES

Jesse H. Brewer, Kenneth M. Crowe, and Richard Johnson (LBL); Alexander Schenck and Robert Williams (U. Washington)

We have continued our study of the depolarization of positive muons in condensed media, using the apparatus designed previously for the measurement of the muon magnetic moment. Some of the subjects accessible to study by muon depolarization techniques are crystal structure, spin relaxation by paramagnetic ions, semiconductors, muonium chemistry, muonium "hot" chemistry, and free radicals containing muonium.

By observing the time dependence of the polarization of positive muons stopped in various media, one can use muons to probe internal magnetic fields, much as the proton is used in NMR. We found that when polarized muons were stopped in a single crystal of gypsum ($CaSO_4 \cdot 2H_2O$) in a transverse magnetic field, the muon precession signal displayed "beats", and a microsecond-scale relaxation of the polarization occurred; these effects were strongly dependent upon the orientation of the crystal in the external field.[1] These results can be explained by the assumption that the muon occupied a normal proton site and experienced local fields due to the dipole-dipole interaction with adjacent protons.

Muon spin relaxation times in various solutions of ferric and manganese ions were studied at concentrations higher than those studied by NMR. Dependence of the relaxation times on temperature and concentration deviated from the behavior predicted by extrapolation of the proton results.[2]

The apparent initial magnitude and direction of the polarization of muons stopped in solution often depends strongly upon the concentration of dissolved reagents, due to the nearly instantaneous effect of the "muonium

mechanism." By studying this effect, we have unequivocally verified the theory formalized by Ivanter and Smilga, and in the process learned much about the chemistry of muonium.[3] Figure 1 shows the dependence on concentration of the polarization and phase precession of stopped muons. Chemical reaction rates extracted by this method have turned out (in the case of ferric salts dissolved in water) to be as much as 60 times as high as those predicted on the basis of chemical measurements of analogous hydrogen-atom reactions. When benzene is used as a solvent, there is evidence that a radical analogous to cyclohexadienyl is formed. With the theory of the muonium mechanism extended to include radicals, we can study the subsequent chemical reactions of the radical.

As can be seen, a great deal of unexpected information has been derived from muon depolarization studies; and we expect that as our work continues further applications will be found.

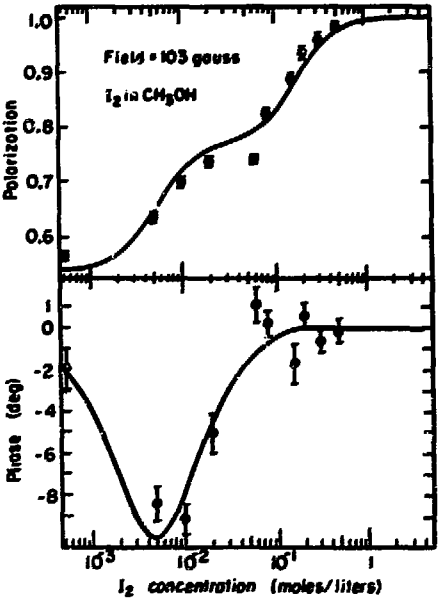

Fig. 1. Dependence on concentration of the polarization and phase precession of stopped muons. In the upper curve the double inflection arises naturally from the theory. The first inflection is related to the muon precession frequency in the 100-gauss external field; the second inflection corresponds to the muon precession in the 1500-gauss muonium hyperfine field due to the electron in muonium. The lower curve shows the phase precession that occurs when the lifetime is comparable to the period of the precession. This verifies the time scale requiring thermalized muonium. (XBL-718-4147)

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S-WAVE π-π SCATTERING LENGTH

T. Maung, G. Masek, E. Miller, H. Ruderman, and W. Vernon (UCSD); K. Crowe and N. Dairiki (LBL)

Differential energy distributions of neutrons from the reaction $\pi^- + p \rightarrow \pi^0 + \pi^0 + n$ have been measured, in collaboration with the University of California at San Diego, in order to study the I = 0, S-wave π-π interaction near the pion-production threshold. The presence of this strong interaction between the final-state pions was expected to show up in the energy distribution of the neutron; its influence can be expressed in terms of a scattering length a_{SO}.

The experiment was performed at the Berkeley 184-in. cyclotron using an incident pi-minus kinetic energy of 378 MeV and laboratory neutron angles of 30, 35, 40, and

45 deg. The basic arrangement consisted of an array of spark chambers to detect the gamma rays from π^0 decays at the point of interaction in the hydrogen target. Neutron counters at the end of a flight path of 20 ft measured the neutron time-of-flight spectrum.

Fitting the distributions with the Chew-Mandelstam solution for the π-π phase shift, we obtain $a_{00} = (0.28 \pm 0.21)\ \mu^{-1}$ for the S-wave π-π scattering length, a value that is in agreement with the current-algebra prediction of Weinberg, the bootstrap calculations of Johnson and Collins, and the most recent forward dispersion relation prediction of Morgan and Shaw. These results have been reported in Phys. Letters.

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

J. H. Brewer, R. J. Budnitz, A. C. Entis, R. M. Graven, R. L. McCarthy, D. H. Miller, and W. N. Rose

An experiment has been in progress to measure the charge asymmetry in the decays $K^0_2 \rightarrow \mu^{\pm} \pi^{\mp} \nu$; an unequal number of positive and negative muons in the decay would indicate a violation of CP conservation. Since the origin of CP nonconservation has not yet been identified, it is crucial that the parameters characterizing the phenomenological description of the K-decay process be accurately measured for comparison with the predictions of alternative theoretical models.

Because a large number of events (10^7) are required for a statistically significant result, we are attempting to measure the asymmetry using counters only; no spark chambers requiring elaborate computer data analysis are used. For this reason, it has been particularly important that background be reduced to an absolute minimum.

The experiment finished data-taking at the Bevatron in January 1971. The analysis has been proceeding smoothly; as of September 1971, it is about 90% finished. The main body of analysis has been done, and we are now in the process of tracking down a number of very small systematic effects. We expect that the asymmetry will be measured to an accuracy of about $\pm 6 \times 10^{-4}$, and that the entire task will be finished by mid-autumn.

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7. A. Schenck, D. L. Williams, J. H. Brewer, K. M. Crowe, and R. F. Johnson, Decay of the Coherent Spin Precession of Polarized Positive Muons in Paramagnetic $MnCl_2$ Solutions, Lawrence Radiation Laboratory Report UCRL-20849, June 1971.

EXPERIMENTAL PHYSICS

Emilio Segrè and Owen Chamberlain in charge

K-MESIC AND Σ^--HYPERONIC X RAYS

Clyde Wiegand

The 500-MeV/c K^- beam at the Bevatron has been used to continue the study of the K^--Mesic and the Σ^--hyperonic atom x rays. Details of x-ray spectra of many elements from Z = 2 through Z = 92 are being measured in order to determine nuclear sizes and to gain a clearer understanding of the interaction of kaons with nuclear matter. In these experiments, negative kaons that stop in matter are captured into Bohr orbits of large principal quantum number n, and form hydrogen-like atoms that undergo de-excitation by the Auger effect and the emission of x rays.

Helium is particularly interesting to us because the K^--α interaction is amenable to calculation and has been extensively studied in He bubble chambers. In recent work, using a Si(Li) detector at the Bevatron, we have obtained the kaonic x-ray spectrum of ^{4}He (see Fig. 1). Three spectral lines corresponding to Bohr orbit transitions n = 3 → 2, n = 4 → 2, and n = 5 → 2 have been measured with a resolution of 340 eV. Intensities per stopped kaon were 0.09, 0.05, and 0.02, respectively. No evidence was seen for transitions to n = 1 (intensity < 0.004). An understanding of the K^--α system is useful for determining the combined parity of kaons and hyperons. For example, are kaons absorbed by the nucleus from s-states or p-states? The present experiment indicates that at least 16% are absorbed from p-states.

Also, we have measured the spectra of the pure isotopes of several rare earth elements. Some of the x-ray lines are found to be broadened due to hyperfine structure (coupling of the kaon orbital momentum to the quadrupole moment of highly deformed nuclei). One of the lines of chlorine has been found to be broadened and its energy shifted due to the

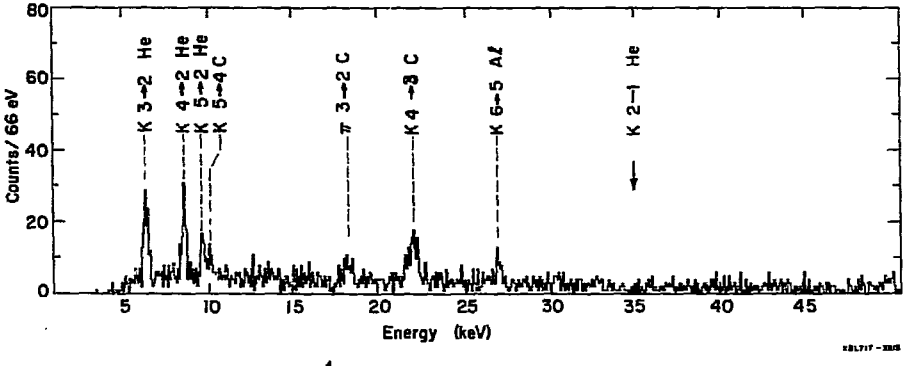

Fig. 1. Kaonic x-ray spectrum of ^{4}He with energy resolution 340 eV. Lines from C and Al came from particles stopped in the graphite energy degrader and the Al structure of the target.

strong forces between kaons and nuclei.

Some of the negative kaons, when absorbed by nucleons, result in the production and release of Σ^- hyperons. The hyperons remain in the target under investigation and form new and rarer atoms, Σ^--hyperonic atoms. The new atoms also emit characteristic x-ray spectra, and their x-ray lines appear along with the kaonic x-ray lines. One of the ultimate goals in the study of hyperonic atoms is a measurement of the Σ^- magnetic moment which is revealed by splitting of the x-ray lines into doublets (fine structure).

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

Gary D. Cable, Roger H. Hildebrand, Chan Pang (University of Chicago); Rae F. Stiening (LBL)

An experiment to search for the rare and possibly forbidden decay mode $K^+ \rightarrow \mu^+ + \nu + \bar{\nu} + \nu$ is in progress at the Bevatron. Whether or not this will be seen depends critically on the nature of the weak interactions. The standard ideas of a current-current interaction suggest that the process should occur, in analogy with the abundant decay $K^+ \rightarrow \mu^+ + \nu$. Since the hadronic current is charged in this case, it may be essentially different from the neutral-current decay processes that have been conspicuous by their absence.

If we do not observe this decay mode, we hope to be able to set an upper limit of 2×10^{-6} on the branching ratio. A result of this sort would set a limit on the possible non-weak interactions of neutrinos as well as eliminate the last remaining possibility for weak neutral currents of appreciable strength.

The major component of the experimental apparatus is an anticoincidence assembly of high-density lead-glass blocks forming a cube 54 cm on a side. Preliminary tests indicate that the gamma-ray detection efficiency of the glass is adequate for the experiment.

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

Steve Shannon

Preparations are well advanced for a measurement at the Bevatron of the asymmetry in the process $\pi^- + p \rightarrow \pi^0 + n$ when the target protons are polarized. This is an experiment long needed in the study of detailed scattering amplitudes for the pion-nucleon system. In earlier years this experiment had been planned but abandoned because the apparatus cost seemed prohibitive. Now the experiment is being prepared as a collaborative experiment with several other groups at this Laboratory, namely, the Moyer-Helmholz Group and Group A. The experiment has been made possible by the demonstration that the semiautomatic scanning and measuring system, SASS, is able to analyze spark-chamber photographs of two-gamma events in the large Moyer-Helmholz gamma-sensitive spark chambers. The running at the Bevatron was started during FY 1971 and continues into the new fiscal year. The measurements should be performed at three beam momenta, probably 1080, 1280, and 1680 MeV/c.

LOW-ENERGY π^-p INTERACTIONS

W. Chinowsky (LBL); D. H. Saxon and J. H. Mulvey (Oxford University)

An experiment to study the reactions $\pi^-p \rightarrow \pi\pi N$ at incident momenta of 456, 505, and 552 MeV/c in the Saclay 80-cm hydrogen bubble chamber has been completed. The most prominent features of the data in the $\pi^+\pi^-n$ final state are a high-mass peak in the $M^2(\pi^+\pi^-)$ spectrum (which moves upward in mass and becomes less significant as the incident momentum increases), and Δ^- production.

The $\pi^+\pi^-$ enhancement can be explained by the introduction of an I = J = 0 $\pi\pi$ interaction. Two forms for this interaction have been investigated: in the Veneziano-Lovelace form, δ_{00} rises approximately linearly from threshold, passing through 90 deg near 720 MeV; the other form has δ_{00} rising from threshold as q^3 for energies less than 450 MeV, and would give a narrower resonance than the first form. The results favor the q^3 form.

There is substantial Δ-production at incident momenta as low as 456 MeV/c (1339 MeV center of mass), rather far below the threshold for production of a Δ of mass 1236 MeV.

Within the framework of an isobar model, we have derived values of the πN partial-wave inelasticities in the S_{11}, P_{11}, P_{13}, D_{13}, D_{33} partial waves, as a function of energy, and have compared these with the predictions of πN elastic phase-shift analyses. We find inelasticity in the S_{11}, P_{13}, and D_{13} waves at lower energies than predicted. The increasing inelasticities obtained here are consistent with the interpretation that P_{11} and D_{13} waves resonate at energies higher than those available in the present experiment.

From these results we have obtained values of the P_{11} branching ratios into πN, $\pi\Delta$, and σN, where σ is an I = J = 0 interacting $\pi\pi$ pair. The πN branching ratio is between 43% at 1339 MeV and 69% at 1402 MeV. The branching ratio between $\pi\Delta$ and σN depends, not surprisingly, on the form of σ used. In the preferred form, the inelasticity is almost entirely through σN; with the Veneziano-Lovelace form, the ratio of $\pi\Delta$ to σN couplings is about unity and increases with energy.

The experiment is continuing with the analysis of further exposures at incident momenta of 415, 590, 670, and 750 MeV/c. All scanning, measuring, and data reduction have now been completed. These data should further clarify the partial-wave parameters, especially the P_{11} and D_{13} amplitudes, to determine resonance properties.

pp AND pd INTERACTIONS

Eugene Colton, W. Chinowsky, W. Gage

An analysis of the reaction $pn \to pp\pi^-$ has been completed. A search for $N^*(1470)$ production among 904 selected examples gives no clear indication at all of the formation of this resonance. The peripheral data are in good agreement with the predictions of a single-pion-exchange model; but at most 5% of the data may be attributed to $N^*(1470)$ production--by some mechanism other than pion-exchange. This finding is in contrast with the results of missing-mass spectrometer experiments and phase-shift analyses of pion-nucleon elastic scattering, which give rather convincing evidence for existence of a T = 1/2, J = 1/2 nucleon isobar at mass of about 1450 MeV/c.[2]

A large paper on two-prong events in pp interactions at 6.6 GeV/c is being completed. The reactions $pp \to pp$, $pp \to pp\pi^0$, and $pp \to p\pi^+n$ are studied.

We also are examining the energy dependence of the reactions $pp \to p(p\pi^+\pi^-)$ and $K^+p \to K^+(p\pi^+\pi^-)$; 33 000 events of the former and 77 000 events of the latter, representing most of the world data, are being analyzed. A detailed analysis of the peripheral $p\pi^+\pi^-$ system is planned in order to determine its partial-wave structure.

An analysis of 7514 $pp \to pp\pi^+\pi^-$ events at 6.6 GeV/c incident beam momentum has been made. We present three types of analyses which argue that a single-pion exchange process is responsible for the dominant peripheral $\Delta^{++}p\pi^-$ production. An angular-correlation analysis suggests that the 1450-MeV

$\Delta\pi$ Deck enhancement is not a pure $J^P = 1/2^+$ state. The demonstration that the absolute magnitude for this enhancement is accounted for by the pion-exchange process indicates that only one process (i.e., pion exchange with diffraction scattering at the π^-p vertex) contributes to the final state, and that a second process need not be added to the pion exchange to account for the observed cross section. Some ad hoc dependence on the $\Delta\pi$ mass must be introduced for a precise fit to the shape of the $\Delta\pi$ mass spectrum, or equivalently to the θ, ϕ angular distributions in the π^-p c.m. system. The $s_{\Delta\pi}^{2\alpha(t)}$ dependence of the Reggeized pion-exchange model of Berger is well known to accomplish this, however, the $\alpha(t)$ with unit slope required by this model is at variance with the apparently rather flat trajectory deduced from data on quasi-two-body pion-exchange-dominated reactions. It is suggested that a $\Delta\pi$ final-state-interaction model may be useful in understanding the reaction.

In our study of pd interactions at 5.9 and 7.8 GeV/c, three-, four-, five- and six-prong events have been measured and are currently being analysed. The project is a companion to studies of the pp interaction. Cross sections, inclusive phenomena, and peripheral resonance production are being investigated.

In particular, we are looking at the dependence on momentum transfer of resonance production observed in selected final states. We intend to isolate reactions of the type $pn(p_s) \rightarrow (p_s)NN + X\pi$, where N represents a nucleon and X is an integer that indicates the number of π mesons produced, and p_s indicates the "spectator" proton. The extraction of pn interactions is being performed with the aid of the impulse approximation and these pn reactions are being compared with their pp counterparts.

T = 2 ELASTIC $\pi\pi$ CROSS SECTIONS

E. Colton (LBL); E. Malamud (NAL); P. E. Schlein (UCLA); A. D. Johnson, V. J. Stenger, P. G. Wohlmut (U. Hawaii)

Experimental differential cross sections from data on the reaction $\pi^-p \rightarrow (\pi^-\pi^-)\Delta^{++}$ at beam momenta of 2.7, 3.0, 3.2, 3.9, and 4.2 GeV/c have been extrapolated to the one-pion-exchange pole to obtain the $\pi^-\pi^-$ elastic scattering cross section. An attempt is made to correct for background due to kinematic overlap with the competing one-pion-exchange process $\pi^-p \rightarrow \rho^0(\pi^-p)$. Analyses done independently on the data in two beam-momentum groupings at ~3.0 and ~4.0 GeV/c give consistent results of a roughly constant 7-11-mb cross section for $\pi^-\pi^- \rightarrow \pi^-\pi^-$ over the dipion mass range 440-750 MeV. Our results are compared with available results from other analyses and with several theoretical predictions for the T = 2 s-wave phase shift δ_0^2.

$\pi^+\pi^-$ ELASTIC SCATTERING

E. Colton (LBL); E. Malamud (NAL)

Experimental differential cross sections from data on the reactions $\pi^-p \rightarrow \pi^-\pi^+n$ and $\pi^+p \rightarrow \pi^+\pi^-\Delta^{++}(1238)$ have been extrapolated to the one-pion-exchange pole to obtain the $\pi^+\pi^-$ elastic scattering cross section from threshold to 1.4 GeV. Consistent results are obtained in three c.m. energy ranges for both reactions. The data have been fitted to several t-dependent extrapolation functions, and the results of the fits are tabulated and plotted as a function of $\pi^+\pi^-$ effective mass. In particular, we find cross sections of approximately 25 and 125 mb, respectively, at the K and central $\rho^0(765)$ mass positions.

POLARIZED-PROTON TARGET DEVELOPMENT

Owen Chamberlain, Raymond Z. Fuzesy, William Gorn, Peter K. Robrish, Stephen R. Shannon

In preparation for Bevatron experiment 142 on negative-pion charge-exchange scattering on polarized protons and in preparation for a polarization experiment at the National Accelerator Laboratory in fiscal 1973 (NAL experiment 61), the polarized-target magnet has been reshimmed to obtain a suitably homogeneous field for a target almost four inches long. A new target material, propylene glycol doped with CrV, has been developed. It has slightly higher hydrogen content than conventional ethylene glycol, while giving the same polarization. It will be used in experiment 142. Preliminary design has been made for a lower temperature cryostat based on cooling the polarized target by the evaporation of helium-3. A preliminary design has also been made for superconducting coils that would allow the direction of the target polarization vector to be oriented in the scattering plane, rather than perpendicular to the scattering plane. These coils would make possible the measurement of the Wolfenstein R and A parameters, especially for π-p scattering. Construction will not proceed until fiscal 1972.

DEVELOPMENT OF PROPORTIONAL WIRE CHAMBERS

Herbert Steiner

We are actively pursuing development and testing of small proportional wire chambers, with intent to capitalize on their unique capabilities as soon as possible. Chambers of 10 cm X 10 cm have been built and tested in Bevatron beams. Satisfactory ways of handling edge effects in the chambers have been developed. Analog methods have been used to allow the PWC's to show graphically the phase space of a beam of particles. We are cooperating with other laboratories in developing inexpensive commercial sources for the electronic circuitry. This involves agreeing in several laboratories on specifications before ordering actual hardware. Our future plans, especially at NAL, rely heavily on this development.

We are continuing to develop and use proportional wire chambers for a variety of applications. A system of chambers has been used at the Bevatron and at the 184-in. synchrocyclotron to measure the profiles and phase space distributions of secondary particle beams. Chambers have been constructed for use with a polarized target in a measurement of polarization in elastic πp scattering. Work is continuing in cooperation with other laboratories in developing relatively inexpensive hybrid electronic circuits for use with proportional wire chambers. A prototype system consisting of 192 channels has been tested and debugged here, and will be used in a Bevatron experiment shortly. We are also building a winding machine for use by experimental groups at LBL, with which large chambers (2 m X 2 m) can be constructed. Construction is starting on the proportional wire chamber system to be used in the Experiment #61 collaboration at NAL.

Our group, in collaboration with others, has been investigating the suitability of various gas mixtures containing xenon. We have found that higher gains in the region of proportional amplification are possible with these mixtures than with the usual standard argon-hydrocarbon gas mixtures.

SPEAR EXPERIMENTAL PROGRAM

Actively participating in preparation of equipment and analysis programs for use at SPEAR (Stanford Positron Electron Asym-

metric Ring) are G. Abrams, C. Freidberg, J. Kadyk (Trilling-Goldhaber) and W. Chinowsky (Segrè-Chamberlain). Construction of the colliding-beam machine at SLAC, begun in 1971, is expected to be completed by spring 1972 and operation for experiments is expected by the end of 1972.

Conceptual design has been fixed for a large solid angle detector, cylindrical in shape, within a magnetic field of ~ 5000 G, and detailed engineering design is proceeding. In particular, at LBL, we shall design and construct a set of electron-shower detectors (each of approximate area 10 ft X1-1/2 ft) capable of identifying pions in a background of electrons that are expected to have an intensity about one-hundred times as high as the pion intensity. Twenty-four such detectors are required to completely surround the circumference of the cylinder. A prototype module has been tested at the Bevatron and the first module of final design will be tested in the fall of 1971. We have taken primary responsibility for writing programs to reconstruct annihilation events from primary data, which will consist of digitized coordinates of tracks in wire spark chambers. These will be pattern-recognition programs to organize spark coordinates into tracks of particles and reconstruction of complete events in space. Further kinematical analysis will identify the particles produced in the e^+e^- annihilation events and ascertain the presence of unobserved neutral particles. It is planned that the parameters of reconstructed events will be available on-line during experimental operations, in order to monitor the progress of the experiment and the performance of the detection apparatus.

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EXPERIMENTAL PHYSICS

George H. Trilling and Gerson Goldhaber in charge

The group is involved in the following projects:

Study of production mechanisms and properties of strange bosons made in the interactions of high-energy K^+ mesons with protons and neutrons. This work is being carried out at 12 GeV/c in the SLAC 82-inch bubble chamber filled with deuterium.

Study of the properties of nonstrange bosons produced by positive pions of momentum around 3.7 GeV/c, using film from the 72-inch Berkeley bubble chamber.

Study of the interactions of Λ^0 hyperons in the momentum range 1 to 5 GeV/c with protons, with much higher statistics than has heretofore been possible. This is done with a special platinum target mounted inside the SLAC 82-inch bubble chamber and exposed to a separated K^- beam. The interactions of the negative kaons provide a copious source of Λ particles. Possibly, interactions of other hyperons (Σ, Ξ) may be studied as well. Several thousand events are expected.

Design of experiments, and testing and development of equipment, principally to study particle production in e^+e^- collisons at SPEAR using techniques such as wire spark chambers and scintillation counters.

K^+d INTERACTIONS AT 12 GeV/c

Alexander Firestone, Gerson Goldhaber, David Lissauer, and George Trilling

We have completed the scanning and measuring on FSD of the approximately 500 000 stereo exposures of K^+d interactions at 12 GeV/c. The film was taken in April 1969 at the SLAC 82-inch deuterium-filled bubble chamber, exposed to a 12-GeV/c rf-separated K^+ beam. Remeasurements have been carried out with the COBWEB system. Since the total number of events in the film is about 850 000, we have restricted our attention at first to events with (1) a visible K^0 or other vee decay, (2) any three-pronged event, or (3) any four-pronged event with at least one stopping track. We have thus measured about 240 000 events of which about 50 000 were remeasured. In addition, we have scanned for antiomega candidates, which are characterized by a vee coming from a charged decay. We have measured the cross sections for the reactions $K^+d \to K^0pp$, $K^0\pi^+d$, $K^0pn\pi^+$, $K^+\pi^-pp$, $K^+\pi^+\pi^-d$, and $K^0\pi^+\pi^-pp$. Results on the analysis to date include the following.

Observation of Antiomega

We have observed an $\bar{\Omega}$ event. The $\bar{\Omega}$ is produced in the reaction $K^+d \to \bar{\Omega}\Lambda\Lambda p\pi^+\pi^-$, and decays via the mode $\bar{\Omega} \to \bar{\Lambda}K^+$. The production cross section is of the order of 0.1 μb. A six-constraint fit to the mass gives $M = 1673.1 \pm 1.0$ MeV, which is in excellent agreement with the known mass of the Ω ($M = 1672.5 \pm 0.5$ MeV). This work has been published in Phys. Rev. Letters.[1]

As a byproduct of the $\bar{\Omega}$ search we have collected more than 65 examples of Ξ production. These events will be used in a search for possible Ξ^* resonances and possible high-mass K^* resonances which decay by the ΞY mode.

K^+n Charge Exchange

We have measured the differential cross section for the elastic charge-exchange reaction $K^+n \to K^0p$ and have found it to be identical to the differential cross section for the line-reversed reaction $K^-p \to \overline{K^0}n$ at 12 GeV/c, and to be in agreement with the predictions of the Regge-pole model of Rarita and Schwarzschild. These data are powerful evidence for strong ρ-A_2 exchange degeneracy. We also find that the forward scattering amplitude is essentially real, and that the cross section for this reaction as a function of incident momentum is identical to that for the reaction $K^+p \to K^0\Delta^{++}$ beyond threshold effects. This work has been published in Phys. Rev. Letters.[2]

Narrow K_N^* Enhancement

In the reaction $K^+n \to K^+\pi^-p$ at 12 GeV/c, we have observed a narrow $K_N^*(1250)$ enhancement at mass M = 1247±5 MeV with width $\Gamma = 20^{+9}_{-6}$ MeV. The enhancement is most probably produced by pseudoscalar exchange; its spin-parity is either $J^P = 0^+$ or $J^P = 1^-$. This work has been written up as a UCRL report,[3] and a preliminary version was included in a paper submitted to the Kiev Conference (1970).[4]

Study of $K^*(1420)$ Region

We have completed a major study of the region of the $K^*(1420)$ in the reaction $K^+n \to K^+\pi^-p$, and report the existence of a new resonance on the low-mass side of the $K^*(1420)$. This new resonance most probably has spin-parity $J^P = 0^+$, and is produced primarily by pion exchange, as is the $K^*(1420)$; but the alternate hypotheses of a $J^P = 1^-$ object produced by a mixture of pion and vector exchanges cannot be completely ruled out at this time. This resonance appears as a shoulder on the low-mass side of the $K^*(1420)$, but is most easily seen through a study of the decay angular distributions in this region. Its mass is M≈ 1370 MeV, its width Γ < 150 MeV. This work has been published in Phys. Rev. Letters.[5]

Structure in the Kπ Mass System

In the same reaction as above ($K^+n \to K^+\pi^-p$), we have observed a significant shift in the angular distribution at a value of M(Kπ) of about 1.85 GeV. The most natural interpretation of the observations is the production by pion exchange of a $J^P = 3^-K^*$ resonance at about this mass, which interferes strongly with background. Such a K^* resonance would presumably be the strange analog of the $J^P = 3^-$ g meson. This work has been accepted for publication in Phys. Letters.[6]

Coherent Production of Q and L

We are studying the coherent production of the $K^+\pi^+\pi^-$ system off the deuteron, i.e., the reaction $K^+d \to K^+\pi^+\pi^-d$. We have determined the cross section for this reaction to be 331±8 μb, where the quoted error is statistical only. This reaction is dominated by production of the Q enhancement in the Kππ system. However, there is also an L signal at about 1700 MeV in the $K^+\pi^+\pi^-$ mass distribution and a d^* signal at about 2200 MeV in the $d\pi^+$ mass distribution. In fact, the L appears to be formed primarily in conjunction with the d^*, with the π^+ meson shared between the two of them. We are studying the structure in the Q and its decay properties into $K^*(890)\,\pi$ and Kρ decay modes. A preliminary version of the results of the analysis of this reaction was presented at the Washington Meeting of the American Physical Society in April 1971,[7] and a complete paper on this reaction will be submitted to Phys. Rev. in the near future.

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π^+p INTERACTIONS AT 3.7 GeV/c

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

A_2^+ Mass Spectrum

Our study of the A_2^+ meson in the reaction $\pi^+p \to pA_2^+ \to p\pi^+\pi^+\pi^-$ has continued. On removing the strong Δ^{++} signal in this channel, we find evidence for a split A_2^+ in the $t' = 0.1$ to 2.0 GeV^2 range. The confidence level for a fit with the "dipole" formula is 53% as against 11% for a fit with a single Breit-Wigner resonance. Here a split is favored, but the Breit-Wigner fit cannot be completely ruled out. We obtain branching ratios for the A_2^+ decay to $\rho\pi$, $\eta\pi$, $K\bar{K}$, and $\eta\pi\pi$ which are in good agreement with other experiments.[1]

Interfering Resonances and the A_2

We have investigated the possibility that an interfering resonance model can reconcile the different A_2 mass spectra observed in different experiments. We find that good fits to the presently available $A^{(+,-,0)}$ missing-mass and three-pion mass spectra are possible over a range of masses and widths of the two resonances. In particular, we find situations where only a small change in the relative phase is required to pass from the split A_2^- spectrum observed in missing-mass experiments to the unsplit A_2^+ spectrum at 7 GeV/c.[2]

Search for C Violation Via ρ^0 Interference

We have theoretically analyzed the $\rho^0 \to \pi^+\pi^-\pi^0$ decay mode and have detailed the possible ways the existence of such a decay could distort distributions of the ω, which normally decays to $\pi^+\pi^-\pi^0$. It is shown, for example, that the ω decay Dalitz plot may be used in a search for a $|\Delta I| = 0$, C nonconserving decay of the ρ^0 to $\pi^+\pi^-\pi^0$.[3]

Charge Asymmetry on the ω Dalitz Plot

An analysis of the $\omega \to \pi^+\pi^-\pi^0$ decay Dalitz plot has been performed for about 4000 ω events from the reaction $\pi^+p \to \pi^+p\omega$. A subsample of the data produced in the kinematic region defined by the conditions

(a) $\Delta^{++}(1236)$ opposing the ω, and

(b) $t' = |t - t_{min}|$ in the interval 0.08 to 0.20 $(GeV/c)^2$

has been found to show an asymmetry over the Dalitz plot, with a predominance of energetic π^+'s.[4]

Regge-Pole Effects in $\rho^0\Delta^{++}$ and $\omega^0\Delta^{++}$ Production

A detailed study of $\rho^0\Delta^{++}$ and $\omega^0\Delta^{++}$ production has been performed via analyses of production and decay angular distributions. The data are found to favor simple models based on the exchange of Regge poles.[5]

Model for $V^0\Delta^{++}$ Production

A theoretical analysis of the $\rho^0\Delta^{++}$ and $\omega^0\Delta^{++}$ data with a π-B exchange-degenerate model has been applied with quantitative success. It is shown that for each reaction the s and t dependence of the data may be understood for the dominant production mechanisms.[6]

Comparison of $\Delta\eta$ and $\Delta\eta'$ Production

We have studied the production mechanism of the quasi-two body state $\Delta\eta'$, and compared the results with our data on $\Delta\eta$ production. It is found that a Reggeized A_2 exchange model adequately describes both reactions.[7]

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Λp INTERACTIONS FROM 0.5 TO 5 GeV/c

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

An experiment to study Λp interactions has been done at SLAC, using the 82-in. bubble chamber with a platinum plate mounted inside. The experiment is similar to one previously performed in the LBL 25-in. hydrogen bubble chamber, in which the technique of using the internal platinum target was developed and first used. The Λ particles are produced by interactions of a 12-GeV/c K^- beam incident upon the plate, and have approximately the momentum range 0.5 to 6.0 GeV/c. About one-sixth of the total data has been analyzed relating to the reactions

(1) $\Lambda p \rightarrow \Lambda p$ (elastic scattering)

(2) $\Lambda p \rightarrow \Lambda p \pi^+\pi^-$.

Over 150 of these event types have been studied.[1]

Results include: (a) a steep momentum-transfer fall-off, corresponding to a strong forward scattering for reaction (1). By characterizing this as e^{-bt}, we find that the slope parameter b is 6.4 ± 1.0 for Λ momenta above 2 GeV/c, to be compared with 6.3 for pp collisions in the same energy region. (b) The en-

ergy dependence of the angular distribution for reaction (1) is now approximately known, using the data from the previous experiment at lower energies. The distributions are nearly isotropic below 600 MeV/c, while P-wave and some D-waves are needed at ~ 1000 MeV/c. At about 2000 MeV/c, a very strong forward peak is seen, with almost no backward peak, and this becomes even more strongly peaked above 3 GeV/c. (c) Reaction (2) is dominated by $\Delta(1238)$ formation, and $\Sigma(1385)$ formation by means of isovector exchange. There seems to be almost no evidence for K^* exchange as would be indicated by a backward peak in the angular distribution. (d) The elastic scattering cross section is ~ 10 mb over this energy region, but until further data are analyzed, a precise valve cannot be reported.

When the experiment is completed, over 200 000 Λ particles will be contained in the data, yielding about 400 Λp interactions visible in the photographs. This is about 10 times previously existing world data for this energy range. Both elastic and inelastic reactions will be studied, yielding much more precise determinations of cross sections, angular distributions, and polarization than previously available.

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SPEAR PROJECT

G. S. Abrams, J. A. Kadyk, G. Goldhaber, and G. H. Trilling

In collaboration with SLAC and UCSD, and others at LBL we are helping to develop a detector to be used in the first experiments at the SLAC positron-electron colliding beam facility, SPEAR, scheduled for initial operation in the fall of 1972. A series of tests at SLAC were performed to study the feasibility of using multiwire proportional chambers[1] as part of a quantameter for detection of electron showers. Part of the SPEAR shower detector may incorporate such a quantameter to identify electrons and to measure position and energy for gamma rays resulting from e^+-e^- interactions.

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THEORETICAL PHYSICS

Geoffrey F. Chew, Group Leader

The LBL Theoretical Group is concerned with the following areas of general laboratory interest: particle theory, design of particle accelerators and related equipment, nuclear physics, atomic physics, plasma physics, and the training of Ph.D. students. Our staff includes ten faculty members from the Berkeley Physics Department and eight LBL senior staff members. There is also a substantial number of temporary postdoctoral researchers, although only three in this category are supported by Laboratory funds. The faculty members receive about three quarters of their support from the University.

PARTICLE THEORY

Heavy emphasis is given to particle theory, particle physics being the primary concern of the LBL Physics Division. Seven faculty men and three members of the LBL senior staff are active in this area, as are most of our temporary postdoctoral people.

For many years a central role in LBL particle-theory research has been played by the concept of the S matrix--the collection of all particle reaction amplitudes. (The S matrix represents the totality of conceivable knowledge about the subatomic world.) LBL S-matrix research is proceeding in a variety of distinguishable directions:

S-Matrix Properties and the "Real World"

Efforts are being made to relate general S-matrix properties to the causal structure of space-time events in the "real world" of laboratory experience. Recently Stapp has been examining the philosophical and physical content of quantum theory[1,2] and has developed new arguments that the entire content resides within the S matrix. A concrete illustration is the motion of an electron in a classical electromagnetic field. Stapp has been able to demonstrate in detail that general S-matrix principles lead here to the same (correct) predictions as are given by conventional quantum field theory.[3] Also shown by Stapp in recent work is that a certain formula, which plays a key role in analytic S-matrix theory by specifying certain basic discontinuities, follows in a formal sense from field theory.[4] (Much attention has been directed to this basic discontinuity formula during the past year because of its relevance to the so-called inclusive cross sections. See below: Regge Asymptotoic Behavior.)

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Hadron S-Matrix Bootstrap Hypothesis

The hadron bootstrap hypothesis states that classical space-time properties prescribe a unique S matrix which approximates strong-interaction phenomena. Arguments have been given by Chew[1] that the special properties of electromagnetism are so intertwined with the

conceptual framework of observational science as to preclude a derivation of electromagnetism from a "scientific bootstrap"--that is, from self-consistency conditions framed in conventional scientific language. On the other hand, strong interactions, being remote from the real world of observation, may be amenable to a scientific hadron bootstrap based on S-matrix self-consistency.

Investigation of the hadron S-matrix bootstrap hypothesis usually proceeds through models based on small parameters that justify some simplification of the full set of S-matrix constraints. The multiperipheral model, where the small pion mass motivates the neglect of all but a tiny subset of singularities, has recently been receiving intensive LBL scrutiny: (a) Snider and Tow[2] have shown that the predictions of the original simple form of the model[3] are not qualitatively changed by inclusion of interference terms corresponding to the interchange of pion "order" along the multiperipheral chain. The kernel strength, in particular, remains too weak to fit known experimental facts. (b) Avalos[4] has shown that inclusion in the model of K's and η's, as well as π's, gives only a small increase in kernel strength, but a substantial increase can result from plausible off-shell forms of the low energy $\pi\pi$ amplitudes. Avalos and Webber have used the Dürr-Pilkuhn form factors[5] to achieve an adequately strong multiperipheral kernel. One manifestation of their success is the successfully predicted rate of increase with energy of the average multiplicity of produced π's and K's. (c) Webber[6] has further calculated the transverse momentum distribution of pions and found it to be in agreement with experiment. (d) Chan, in a rough multiperipheral calculation of the meson-baryon total cross section, found a result in reasonable accord with experiment. (e) Chew and Snider[7] have generalized their study of a mechanism by which the leading Regge pole in the simple model is split into two poles plus a branch point, through the action of a weak high-subenergy component in the multiperipheral kernel. The upper of the two poles is identified as the Pomeron (P) while the lower is supposed to be the P'. Sorensen has been further refining the aforementioned high-subenergy kernel by numerical attention to the self-consistent contribution from the Regge branch point as well as from the poles. Shei also has been analyzing this self-consistency constraint but from the point of view of a unitarity bound. He has shown that a leading Regge pole emerges only if the low-subenergy kernel is not too strong. Otherwise the leading singularity must be a branch point.

A bootstrap model closely related to the simplest form of multiperipheral model is the strip model, which received recent encouragement from calculations by Collins and Johnson.[8] Webber, however, has found by more careful calculations that the Collins-Johnson results are misleading and that the $\pi\pi$ form of the strip model employed by these authors is incapable of close correspondence with experiment.[9] This conclusion has been reinforced in an independent investigation carried out by Chen.

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Regge Asymptotic Behavior

The mathematical and experimental significance of Regge asymptotic behavior is being investigated. The extension of the hypothesis of Regge behavior to multiparticle S-matrix elements has received impetus in recent years from dual-resonance models (see below) and from the realization that the hypothesis is directly relevant to inclusive cross sections. There has been LBL participation in both these developments, which often are interrelated. (a) Einhorn has investigated the possibility of finite-energy sum rules for single particle inclusive production near the boundary of the fragmentation region,[1] while Cahn and Einhorn have studied the consequences of internal symmetries for inclusive processes, finding many experimental predictions. Cahn and Einhorn also have been studying the criterion, analogous to exoticness in two-particle reactions, that would correspond to a vanishing non-Pomeron discontinuity in a three-particle reaction. A controversy has developed in this area, differing criteria having been proposed in the already published literature.[2,3] Cahn and Einhorn, on the basis of the dual resonance model and with assistance from M. Green, have arrived at a rule different from any so far proposed. (b) On the basis of Pomeron dominance, Webber has shown that in the process

A + B → C + n charged particles + anything else,

C being any combination of detected particles (including none at all), the average value of n should have the asymptotic energy (s) dependence

$$\bar{n}_{ABC} \underset{s \to \infty}{\sim} k \log s + f_{ABC}(p_C)$$

where k is a constant independent of ABC. The same result has been obtained independently by Nieh and Wang.[4] Webber is now investigating the prediction for f_{ABC} given by various models. (c) Risk, in collaboration with Friedman and others,[5,6] has undertaken a systematic analysis of multiparticle production data in order to check the factorization principle--an important aspect of the Regge-pole hypothesis. Risk also is comparing more detailed models for multiple production with currently emerging experimental data.[7,8,9,10,11]

Two-particle reactions continue to receive attention in Berkeley. (a) Field and Jackson have been analyzing the reactions $K^- n \to \pi^- \Lambda$ and $\pi^+ n \to K^+ \Lambda$ from the Regge-pole, duality, standpoint, using both high- and low-energy data, including polarization measurements. This study has thrown light on the relative importance of secondary Regge trajectories. Field has extended the study to the reaction $\pi^- p \to \pi^0 n$ and makes the general hypothesis that high-energy two-particle reactions, including polarization, can be well approximated by exchange-degenerate leading trajectories plus exchange-degenerate daughter trajectories (lower by one unit of angular momentum) plus the standard Pomeron-Regge cuts. (b) Austin and Rarita have used a Regge-pole fit of pp and $p\bar{p}$ cross sections and polarizations[12] up to 70 GeV to predict elastic pp scattering at the energies and momentum transfers accessible to the CERN intersecting storage rings. Their prediction, which corresponds to a Pomeron slope of 0.31 GeV^{-2}, is in agreement with initial ISR measurements. (c) Dubovoy and Suzuki have examined the implications for $K^+ p$ elastic-amplitude finite-energy sum rules arising from the assumption of direct-channel helicity conservation at high energy. They have found evidence for at least one fixed pole in the complex J-plane.

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Dual-Resonance Model

In the program of unitarizing the dual resonance model, diagrams with closed loops are encountered. Kaku and Yu[1,2,3,4] have developed a general set of rules for closed-loop formulas and have given simple interpretations thereof. The existence of these rules will facilitate unitarity corrections to the simple version of the model--which ignores all nonlinear unitarity constraints.

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"Classical" S-matrix Theory

A variety of S-matrix investigations have been carried out which make no use of Regge behavior; the ingredients are the "classical" principles of analyticity, unitarity, and Poincaré invariance. (a) Field has attempted to find an energy continuation connecting measured πN phase shifts at 26 different momenta between 385 and 1700 MeV/c. His "best" path agrees for the most part with paths found by other groups, but there appear to be additional resonance structures in the P31, D35, and P13 partial waves between 1400 and 1700 MeV/c.[1] (b) Chan has studied the dynamical interplay between two nearby resonance poles of the same quantum numbers.[2] Data on the A_2 meson have been discussed on this basis.[3] (c) Mathews has used the Khuri-Treiman dispersion relation to numerically calculate the pion distribution in the decay $K \to 3\pi$ in terms of the $\pi\pi$ scattering amplitude. Inclusion of both P and S waves allows agreement with observed data.

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Field-Theoretical Studies

In addition to particle theory research based directly on the S-matrix concept, there is substantial LBL activity employing the notion of interactions localized in space-time. For weak and electromagnetic interactions, the local-field (or current) concept plays an indispensable role. For strong interactions such concepts may not be required, but currents have proved useful in the formulation of certain models. For models where the small pion mass is crucial, for example, it is often useful to associate a local current with the pion and then to employ the techniques of current algebra.

Suzuki and collaborators have been investigating a variety of problems involving strong, weak, and electromagnetic interactions, using field-theroetical sum rules. (a) Langacker and Suzuki have derived a class of inequalities for the integrated e^+e^- cross section for annihilation into hadrons through one photon.[1] The inequalities are applied to estimate a lower bound on the hadronic contribution to the muon magnetic moment and also to test some predictions on the asymptotic behavior of the annihilation cross section. (b) Langacker has shown that a large value for the parameter λ_+ of $K_{\ell 3}$ decays (e.g. $\lambda_+ = 0.045$) is not compatible with ρ saturation of the isovector electromagnetic current spectral function. Also discussed have been implications for the Weinberg mass rules and c-number Schwinger terms.[2] (c) Shei and Suzuki have derived sum rules for differential inclusive cross sections from current-algebra equal-time commutation relations.[3] The sum rules hold at high energies and relate integrated cross sections for different charge states of the detected secondary.

Dubovoy, Langacker, and Suzuki have investigated weak-interaction contributions to two-hadron reactions in the energy region accessible to the NAL accelerator. The standard current × current model was employed to calculate differential cross sections (including polarization effects) for strangeness-changing processes, as well as the interference of weak with strong amplitudes in "allowed" reactions.

Moorhouse and collaborators[4] have been studying high-energy pion photoproduction, where striking regularities have been observed that are not accommodated by simple Regge-pole models. Dispersion relations in this work are supplemented by a quark model. Moorhouse's approach is not really field theoretical, but in using the quark concept it goes beyond S-matrix theory.

A hybrid approach also has been employed by Shei and Tow[5,6] in constructing a multiperipheral model of deep inelastic electron-nucleon scattering. Baryon links in the multiperipheral chain here are assigned the parton role of "pointlike" photon absorbers.

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PARTICLE ACCELERATORS

Theoretical aspects of the design and operation of high-energy particle accelerators form the major research interests of four of the Theoretical Group senior staff. Within the last year, almost all of the effort of these men has been devoted to support of the LBL Electron-Ring Accelerator (ERA) project.

Work not associated with the ERA project has included contributions by A. Garren to the design of the LLL 5-MeV storage ring; participation by A. Garren, L. Smith, and A. Sessler in the SLAC Summer Study of Supersloop; and a first look at a proton-electron-positron colliding beam system.[1]

The major portion of the ERA work has been in support of the present experimental program on ring formation (Compressor 4), with some effort devoted to preparation for experiments on ring acceleration (Compressor 5),[2] and some small effort devoted to consideration of aspects of full-scale accelerators.[3,4] In connection with Compressor 4, single-particle dynamics has required a certain amount of attention,[5,6] but almost all of the theoretical effort has gone into the study of beam instabilities.

The concentration of effort upon coherent instabilities was most natural, as during the year the experimental ERA work was dominated by the identification and study of those instabilities which severely limited the formation or rings of high intensity and good quality. Unstable oscillations can be suppressed by suitably designing the surrounding wall structure (as was described in a review paper[7] and extensively studied analytically and computationally[8,9]), and by enhancement of the Landau-damping coefficients that measure the extent to which spread in particle parameters acts to detune the resonance.[10,11,12] Work was also devoted to developing measurement techniques for elucidating the nature of a coherent instability.[13,14]

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NUCLEAR PHYSICS

For many years Swiatecki and his collaborators have been concerned with the properties of nuclear matter. At present their work is on two levels. First, several concrete problems in nuclear structure are being investigated, some in collaboration with members of the Nuclear Chemistry Division. The underlying theme in this work is the unification of nuclear theory, a guiding prinicple being the ordering of nuclear effects according to the magnitude of the relevant energy terms in the Hamiltonian. An energy hierarchy in decending powers of the cube root of the nuclear mass number A is found to be useful, terms of order A, $A^{2/3}$, $A^{1/3}$ being associated with macroscopic (collective) aspects of nuclear structure, and terms of order A^0, ...A^{-1} involving microscopic (single-particle) features.

The semiempirical theory of nuclear masses, sizes, and shapes, formulated by Myers and Swiatecki some years ago, embodies this approach, and work on these static aspects of nuclear structure continues. More recently, a beginning in the formulation of the dynamics of heavy-ion collisions has been made.[1] The immediate stimulus here is the need to develop guidelines for the projected attempts to produce superheavy elements by heavy-ion bombardments.

A second set of problems is more loosely related to possible applications in nuclear physics. One study that has gone on for a number of years is the classification and analysis of the configurations of equilibrium of rotating, gravitating, or charged fluid masses, endowed with a surface tension. Another study, carried out together with J. Lindhard concerns the stability of extremely heavy nuclear systems with atomic numbers in the thousands or more. In particular, the stability of hollow systems (nuclear 'soap bubbles') was investigated. It was found that when the atomic number exceeds (in order of magnitude) the three-halves power of the reciprocal of the fine-structure constant, the atomic electrons surrounding the nucleus become highly relativistic and collapse onto the nuclear soap bubble. The hollow electron cloud thus formed, which may be treated as a relativistic Thomas-Fermi gas, screens off the nuclear charge and appears to restore to the combined system of nucleons and electrons the attributes of neutral stability against disintegration. Whether this is sufficient to endow such structures with a finite probability of existence in the universe, and how one would search for them, has not been analyzed.

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ATOMIC PHYSICS

Members of the Theoretical Group have been concerned with a variety of problems in atomic physics. In particular, because of recent progress in the measurement of the fine-structure constant,[1] using the Josephson effect, there has been interest in theoretical work which leads to the determination of a precise value by other means. Thus Daley and Schwartz have made relativistic and nuclear-motion corrections to the fine structure of the 2^3P state of helium which will allow a determination

of the fine-structure constant to an accuracy of one part in a million.

Related work by Wichmann and Mohr is concerned with radiative corrections to the energy levels of an electron in a strong Coulomb field.

In connection with experiments by Marrus and Schmieder[2] at the HILAC, Schwartz has made an accurate analysis of the magnetic dipole decay of the $1s\,2s\ ^3S$ state in two-electron atoms. This work is in good agreement with experiment.

There have been studies by Watson and his collaborators on the collisional excitation of helium ions by atomic hydrogen. The cross section for the excitation of atomic hydrogen to the 2p state has also been determined. Watson has also studied the scattering and energy loss of light in rarefied media. This work is of interest for the propagation of light in intergalactic and interstellar media

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PLASMA PHYSICS

Two theorists are active in the field of plasma physics, Kaufman and Watson. Kaufman and his co-workers are concentrating on the interaction processes among collective modes, and between particles and modes. Recent research includes (1) resonance broadening for discrete-mode interactions; (2) particle-mode interactions in cylindrical systems, and the consequences thereof; (3) diffusion theory for damped and growing waves; (4) stability studies for gravitational systems; (5) evolution of large amplitude waves in non-uniform media; (6) diffusion processes in toroidal systems.

Watson and his students Kuo and Lau have been concerned with the propagation of electromagnetic waves in plasmas.

GRADUATE STUDENTS

The major fraction of the research reported here is carried out by graduate students working to complete the requirements for the Ph. D. degree in theoretical physics. During the past year there have been 20 to 25 graduate students in the Theoretical Group, of which about one-third are supported by University funds. During this year, 10 students have completed requirements for the Ph. D. degree.

As in most research groups, there are in ours a small number of disconnected research efforts which do not conform to the pattern of this report. Such research is carried out by theorists who also contribute to the thrust of our principal programs. Examples of this work include the following studies:

(a) Work by Coakley and Watson on the factors which influence the earth's climate. These theorists are engaged in an effort to determine the relation between the earth's orbital parameters, which influence the solar flux, and its climate.

(b) Studies by Lepore and Riddell dealing with hydrodynamic instabilities and the turbulent transport of heat.

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ATOMIC BEAM GROUP

Howard A. Shugart in charge

The research effort of the Atomic Beam Group is directed primarily toward measuring some of the electromagnetic and mechanical properties of atoms, molecules, and nuclei, and toward testing various fundamental concepts of physics. Most of this work is performed on simple atomic systems so that the interpretation of results is unambiguous and the comparison with theoretical predictions especially favorable. Our methods make use of atomic and molecular beams, ion beams, optical and electron pumping, and radiation and particle detectors. In most cases these techniques are noted for their sensitivity and reliability. We are specially fortunate to have a mass-spectrometer operating on one of our beam apparatuses, which allows a number of interesting problems in stable atomic species to be investigated.

HYDROGENLIKE AND HELIUMLIKE ATOMS

Robert Schmieder and Richard Marrus

Lifetimes and spectra of hydrogenlike and heliumlike ions of high Z have been determined by accelerating atoms down the Berkeley Hilac and into a beryllium-foil target. Emerging excited ions give off characteristic x rays that are detected by lithium-doped silicon detectors.

The lifetime of the $2^2s_{1/2}$ state of hydrogenlike Ar-XVIII was measured by direct observation of spontaneous two-photon decay in a beam-foil time-of-flight setup. Identification of the two-photon mode was made using photon counting techniques to observe the single-photon continuum and the peak resulting from summing the energies of photon pairs detected in coincidence. The measured lifetime, $\tau(2^2s_{1/2}) = 3.54(25)\times10^{-9}$ sec (95% C. L.), is in excellent agreement with theoretical predictions.[1,2]

The lifetime of the $1s2s\ ^3S_1$ state of heliumlike Ar-XVII has been measured by observing the decay in flight of the metastable component of the fast foil-excited beam. The decay occurs predominantly by relativistic magnetic dipole emission, a process first discussed by Breit and Teller. The result, $\tau(2^3S_1) = (172\pm15)\times10^{-9}$ sec (95% C. L.), is compared with a recent calculation[3] which predicts a value of 210 nsec—close enough to be interesting but far enough away to encourage further effort.[4-6]

New experiments are planned on the Superhilac when its modifications are completed. In the meantime, we are working on the instrumentation that will be needed.

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HYPERFINE STRUCTURE OF ^{69}GA

J. Yellin and Richard Marrus

In recent years, several experiments have been reported in which electric fields were used in the C-region of an atomic-beam apparatus. Some of these experiments were concerned with a study of the Stark effect while others took advantage of the Stark effect as a means of tuning energy levels. In all of these experiments the electric field was used either alone or in parallel with a magnetic field, except for possible accidental off-axis field components. Most atomic-beam experiments involving electric fields have been on $J = 1/2$ states (e.g. alkalies) whose interaction with an electric field is a scalar and therefore independent of the field direction. More recently, atomic-beam electric-field experiments involving gallium, indium, and thallium have been reported. Atomic beams of gallium and indium usually contain both the ground $^2P_{1/2}$ state and the metastable $^2P_{3/2}$ state; and thus regardless of which state is the object of study, both are present. Since the $^2P_{3/2}$ state possesses a tensor polarizability, the direction as well as magnitude of the electric field is important in determining the combined Zeeman-Stark effect.

Using gallium-69 as an example, we have examined the influence of crossed fields on the $^2P_{3/2}$ state and have concluded on the basis of a theoretical analysis that the observation of anti-level crossing in ground and low-lying metastable states should be possible by the atomic-beam method provided transitions between the crossing levels lead to a refocused beam. Detection of anti crossing by atomic beams would have the advantage that no light would be required, in addition to the usual advantage of beams.[1,2]

1. J. Yellin, Combined Zeeman and Stark Effect in the Hyperfine Structure of the $6^2P_{3/2}$ State of Thallium-205 and the $4^2P_{3/2}$ State of Gallium-69, Lawrence Radiation Laboratory Report UCRL-19569, Mar. 1970, submitted to Phys. Rev.
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DIFFERENTIAL STARK SHIFT

Joseph Yellin

The observation of Stark splitting in optical transitions by the atomic-beam method utilizes unpolarized light, for the nature of the detection is such that it is unnecessary to establish a population difference among the magnetic sublevels of either the excited state or the ground state. Nevertheless, several advantages are gained from selective excitation of magnetic sublevels by means of polarized light: one, it is possible to eliminate the need for the alkali D-line filters by use of a linear polarizer only; two, the breakdown of hyperfine coupling by the electric field can be explored.

Cesium is a particularly attractive system in which to study the effect of using polarized light, for due to its large fine-structure interaction, two resonances (one due to the $^2P_{1/2}$ state and the other to the $^2P_{3/2\pm3/2}$ state) overlap, so that ordinarily it has been necessary to use D-line filters to measure the differential Stark shift in the $6^2P_{3/2}$ state. Moreover, the large electric fields which are needed for cesium result in a complete breakdown of the hyperfine coupling in the $^2P_{3/2}$ state.

Results of a preliminary investigation on cesium show that when the light is linearly polarized perpendicular to the quantum axis, the

selection rule $\Delta m_J = \pm 1$ connects the ground $^2S_{1/2}$ state with both $^2P_{3/2\pm1/2}$ and $^2P_{3/2\pm3/2}$; and consequently we observe the differential Stark shift. When the polarization is parallel to the axis, $\Delta m_J = 0$, only the $^2P_{3/2\pm1/2}$ state can be excited. If the unfiltered cesium lamp is scanned with the light polarized perpendicular to the axis of quantization, the high-field resonance is due to both $^2P_{3/2\pm3/2}$ and $^2P_{1/2}$; whereas if the polarization is parallel to the quantum axis, the resonance is due only to $^2P_{1/2}$. Thus the two resonances may be separated.

The technique should prove especially useful when the differential Stark shifts are comparable to the line width of the exciting radiation or when optical filters may not be used without great loss of intensity (e.g., when the fine-structure splitting is small).[1]

1. J. Yellin, The Use of Polarized Light in the Measurement of Differential Stark Shifts by the Atomic Beam Method, Lawrence Radiation Laboratory Report UCRL-19575, Apr. 1970.

METASTABLE He, Ne, Ar, Kr, Xe, H_2, D_2

Charles E. Johnson, Robert S. Van Dyck, Jr., and Howard A. Shugart

A time-of-flight technique has been used to investigate the lifetime of metastable states of He, Ne, Ar, Kr, Xe, H_2, and D_2. The technique was originally developed to measure the two-photon, radiative lifetime of the 2^1S_0 metastable state of He.

After passing from a cooled source, helium atoms are excited by a pulsed, antiparallel electron beam. The atomic beam then contains not only ground state helium atoms but also metastable atoms in both the 2^3S_1 and the 2^1S_0 states. The metastable atoms are detected at two positions, 1.9 meters and 6.7 meters from the electron gun, by Auger ejection of an electron from a copper target, the first of which is a 60% transmitting mesh. Ground state helium atoms cannot cause an electron to be ejected and hence are not detected. The time-of-flight distribution for the metastable 2^1S_0 state is separated from that of the 2^3S_1 state by illuminating the beam with an rf-discharge helium lamp. The 2^1S_0 state is quenched by resonant absorption of a 20 581 Å photon, raising the atom to the 2^1P_1 state, which then decays preferentially to the $^1S_0$ ground state for the triplet system. The time-of-flight distribution for the 2^1S_0 atoms is therefore obtained from the difference between the full beam and the quenched beam. A comparison of the number of 2^1S_0 metastables within a given velocity interval at the two detectors determines the number which decay in flight and yields a value for the two-photon radiative lifetime. The value of the singlet lifetime for both He^3 and He^4 is 19.7 ± 1.0 msec, agreeing with the theoretical value of 19.5 msec, but disagreeing with the value 38 ± 8 msec measured by Pearl using a movable detector. The 1.0-msec error is an estimate of the remaining systematic errors in the experiment.[1-4]

After completing the measurement of the radiative lifetime of the 2^1S_0 metastable state of He, preliminary results have been obtained for the $^3P_0$ and $^3P_2$ metastable states of the heavier noble gases as well as for the $c\ ^3\Pi_u$ metastable state of H_2 and D_2. The lower limits for the long radiative lifetimes of the heavier noble gases are: $\tau(^3P) > 0.8$ sec for Ne, $\tau(^3P) > 1.3$ sec for Ar, and $\tau(^3P) > 1.0$ sec for Kr. Xe yields a composite decay curve possibly resulting from other long-lived states cascading to the ^3P states. The present measurements are limited by residual gas or beam-beam scattering, and by the length of the time-of-flight region being short compared with a decay length.[5]

For H_2 and D_2, the radiative lifetime for a combination of magnetic dipole, electric

quadrupole decay of the v = 0 e $^3\Pi_u$ metastable state to the repulsive $^3\Sigma_u^+$ state is $\tau = 1.0 \pm 0.1$ msec. Experiments are in progress to extend our measurements on H_2 and D_2 to include HD, and also to investigate the $a\,^3\Pi_u$ metastable state of CO.[6]

1. R. S. Van Dyck, Jr., C. E. Johnson, and H. A. Shugart, Radiative Lifetime of the Metastable 2^1S_0 State of Helium, Phys. Rev. Letters 25, 1403 (1970).
2. Robert Spaulding Van Dyck, Jr., Radiative Lifetime of the 2^1S_0 Metastable State of Helium (Ph.D. Thesis), Lawrence Radiation Laboratory UCRL-20142, Nov. 1970.
3. R. S. Van Dyck, Jr., C. E. Johnson, and H. A. Shugart, Radiative Lifetime of the Metastable 2^1S_0 State of Helium, Bull. Am. Phys. Soc. 15, 1516 (1970).
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SPINS, HYPERFINE STRUCTURE, MAGNETIC MOMENT OF CESIUM ISOTOPES

O. B. Dabbousi, M. H. Prior, and H. A. Shugart

We have used the atomic-beam magnetic resonance method to determine the ground state nuclear spin, the electronic $^2S_{1/2}$ ground state hyperfine structure (hfs) separations $\Delta\nu$, and the nuclear magnetic moments of 45-min ^{125}Cs and 13-day ^{136}Cs. A more accurate value of the hfs separation of 6.2-hr ^{127}Cs was obtained by combining resonances reported previously with those reported in this work. Results are:

Isotope	I	$\Delta\nu(^2S_{1/2})$ (MHz)	μ_I (uncorr) (μ_N)
^{125}Cs	1/2	+8754(40)	+1.40(2)
^{127}Cs	(1/2)← previously measured	+9109(45)	+1.45(2)
^{136}Cs	5	+12702(28)	+3.68(4)

Previously the method of atomic beams has furnished the nuclear ground state spins and magnetic moments for a series of ten cesium isotopes with neutron numbers ranging between 72 and 83. Our present measurements extend this series at the neutron-deficient end (45-min ^{125}Cs) and fill a gap in the neutron-rich end (13-day ^{136}Cs). The latter isotope has 81 neutrons--one less than a closed shell--and 5 protons outside the Z = 50 shell. Thus, we would expect that this nucleus would be spherical, at least in the ground state, and that the shell model would explain the ground state spin and magnetic moment. Our measurements concur with this picture.

The ground state spin of ^{125}Cs and ^{127}Cs cannot be explained easily in terms of the shell model. To obtain a spin 1/2 from five J-J coupled protons, one has to place one of the protons in the $3s_{1/2}$ shell or place all five protons in the $h_{11/2}$ shell. Both of these possibilities are excluded by energy considerations. However, a deformed potential can account for the spin of 1/2.[1]

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RF RESONANCE TECHNIQUE

Tetsuo Hadeishi

The rf resonance technique, because of its high resolution, can yield a great deal of information about the excited states of atoms that cannot be obtained by classical techniques; but unfortunately, its application generally requires a very high-powered rf generator. We have found a way to achieve the resonance effect by means of beam-foil spectroscopy without using an rf generator. Accelerated foil-excited atoms or ions move at a relatively high velocity (a few percent of the speed of light) that is reasonably uniform and quite directional. These atoms, propagating with velocity V through an applied spatially periodic electric field of period 2d, experience an oscillating frequency ν given by $\nu = V/(2d)$. The required rf power is given by the amplitude of the static spatially periodic field; it can easily be made extremely high. Thus the frequency one can create artificially for fast atoms ranges from a few MHz to 10 GHz. If one passes the beam along the channel direction of the crystalline foil, the frequency seen by the atom could be as high as the vacuum ultraviolet region. Therefore, at least in principle, the usable frequency is from a few MHz to the vacuum ultraviolet. At present, no device is available that can be tuned over such a wide range.

We have tested the possibility of producing a resonance effect by means of a spatially periodic electric field by observing the Lamb shift for the n = 2 level in hydrogen. The experimental result is in complete agreement with the theoretical prediction. The beam-foil spectroscopy technique can also be used to detect rf magnetic resonance, Hanle effect, and level-crossing effects. In order to observe such phenomena, it is necessary that the excited atoms be either oriented or aligned. [1]

Since almost no information concerning the alignment of excited states by foil was available, we undertook last year an experimental program to provide some. [2] One feature of the beam-foil light source is that the time (or place) of excitation is sharply defined. This permits the observation of quantum beats; such beats are a sensitive indicator of the presence of alignment of the excited electronic levels. In our experiments, in which $^{20}Ne^{+}$ ions with a nominal energy of 425 keV were sent through a carbon foil 5 $\mu g/cm^2$ thick, we found conclusive evidence that the passage of ions through a thin foil results in a high degree of alignment of the transmitted excited atoms and ions. We have used these observations to measure the mean lives and g values of electronic levels.

One of the very important features of the alignment of the electronic states in the beam-foil experiment is the possibility it presents for studying the ions. In classical optical spectroscopy, determining the g-values of ions is very difficult because of the cyclotron-resonance effect in high magnetic fields. (High magnetic fields are necessary for Zeeman effect measurement because of the Doppler shift.)

However, in the quantum-beats experiment, the Doppler effect contribution is completely negligible, allowing the determination of g-values. These values can be used to check the level-scheme assignments made on the basis of classical spectroscopy. For example, from g-values determined by observing the Ne II line at 4220 Å, we find that the previous assignment of $3d\,^4D\text{-}4f\,^4D^0$ is incorrect. (This was pointed out by Dr. W. C. Martin of the National Bureau of Standards.)

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1. T. Hadeishi, Resonance Effects of Fast-Moving Excited Atoms by Spatially Periodic Potentials, Nucl. Instr. Methods 90, 337 (1970).

2. C. H. Liu, S. Bashkin, W. S. Bickel, and T. Hadeishi, The Alignment of Atoms and Ions with the Beam-Foil Light Source, Phys. Rev. Letters 26, 222 (1971).

TEST FOR MERCURY IN FOOD

T. Hadeishi and R. D. McLaughlin

A problem of great importance today is the detection of mercury in food, especially in fish such as tuna and swordfish. Unfortunately, so far as we know, no device available can make a rapid analysis of mercury to about 0.1 ppm in about 1 min without first separating the mercury from the host material. Because of the urgent need for the detection of mercury, we have converted to this purpose a mercury optical-pumping nuclear magnetic resonance magnetometer which we had constructed earlier to measure magnetic fields.[1] We were motivated to utilize this technique because we are able to observe routinely in our magnetometer a magnetic resonance signal whose equivalent density is about 10^{10} to 10^{11} atoms per cm^3. This corresponds to about 10^{-12} g of mercury per cm^3. Because of the intrinsic sensitivity of this apparatus and because considerable work had been done to construct a stable, intense, sharp mercury lamp and associated electronics, we felt that converting the magnetometer to a mercury detector would be of interest.

Our objective was to develop an instrument that can be operated by completely inexperienced personnel (such as fishermen), which has high accuracy in mercury detection (to at least 0.04 ppm), which is very rapid in analysis without any chemical separation from the host material, and which is inexpensive. We believe that the prototype instrument we developed satisfies the above aims, although the unit in its present form is not quite portable because we used readily available materials rather than engineering a commercial-type unit.

1. T. Hadeishi and R. D. McLaughlin, Hyperfine Zeeman-Effect Atomic Absorption Spectrometer for Mercury, Science 174, 404 (1971).

METASTABLE LiII 2^1S_0

M. H. Prior and H. A. Shugart

The radiative lifetime of Li II 2^1S_0 has been measured by counting decay photons versus time from an ensemble of metastable Li ions stored in a simple electromagnetic trap of the Penning variety.[1] The result is $\tau_{expt} = 503(26)$ μsec. The error represents one standard deviation from the mean of a series of 34 separate determinations. This result is in agreement with the theoretical value $\tau_{th} = 513$ μsec.

To the authors' knowledge, this is the first application of the ion storage technique to the measurement of a metastable lifetime.

The method used is manifestly straightforward. A quantity ($\approx 10^2$) of Li ions in the 2^1S_0 state is created at t=0. They are stored in an ion trap in a region (≈ 3 cm^3) viewed by photon detectors capable of counting a constant fraction of the decay photons which leave the region during the confinement time. These counts are accumulated over several mean lifetimes after t = 0. All ions are then swept from the trap, and a new cycle begun. Many fill-store-dump cycles are repeated until a decay curve is built up which has sufficiently small statistical error to allow determination of a mean lifetime.

1. M. H. Prior and H. A. Shugart, Radiative Lifetime of Metastable LiII 2^1S_0, Phys. Rev. Letters 27, 902 (1971).

POLARIZATION OF CASCADE PHOTONS

John Clauser, Eugene Commins, and Stuart Freedman

The polarization correlation of optical

photons emitted successively in an atomic cascade is being measured as a test for the existence of local hidden variables in quantum mechanics. The photons are directed through polarizers and counted in delayed coincidence. An analysis of the coincidence rate as a function of relative polarizer orientation yields a sensitive test for the existence of a relativistically invariant substructure underlying quantum theory. The ignorance of the initial conditions of this substructure, it is hypothesized, give rise to the stochastic results of quantum mechanical measurements. Preliminary results indicate the nonexistence of such a substructure.[1,2]

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CONTROLLED THERMONUCLEAR RESEARCH AND PLASMA PHYSICS

W. B. Kunkel in charge

RESEARCH PROGRAMS

The research activity of this group in plasma physics and related atomic physics is a part of the controlled-fusion program centered at Lawrence Livermore Laboratory. Additional information about this work is included in the Controlled Thermonuclear Research Annual Report.[1]

The theoretical development of the combined Zeeman and high-frequency Stark effects has been completed. This theory, which permits the spectroscopic measurement of the frequency spectrum, intensity, and polarization of sufficiently strong electric fields in a magnetized plasma, has been carried out by numerical solution of Schrödinger's equation and, when possible, by simplified calculations using perturbation theory. Extensive numerical calculations have indicated the range of validity of the results of perturbation theory, and have enabled us to recognize several pitfalls to be avoided in measuring electric fields by this technique. The calculations have also been extended to include hydrogen-like atoms, but so far without including the effects of a magnetic field.

In an experiment in which we apply a known high-frequency electric field to a hydrogen-helium plasma, we are concluding a detailed comparison of the experimental results with the predictions of the theories mentioned above ($\vec{B} = 0$). In a beam-plasma interaction experiment, studies of the electric fields associated with the instability by the high-frequency Stark-Zeeman effect are continuing, and new instrumentation is being developed to facilitate the studies of the temporal growth of the instability.

The spectral distribution of light emitted or scattered from a plasma gives information about fluctuations in the plasma and is therefore being used for diagnostic purposes. Light is characterized by phase as well as by frequency, and during the last year, work was begun on a project designed to explore the possibilities of using phase information for diagnostic purposes. Preliminary studies indicate that with phase information one should be able to make a local spectroscopic measurement and to observe correlation between light sources in a plasma.

A laser-plasma experiment is still under development. Q-switched laser pulses with subnanosecond rise times and various pulse lengths have been successfully demonstrated by using a laser oscillator in the TVR (Time Variation Reflectivity) mode, with a variable length cavity. This fast pulse will be amplified by two 15.2-cm ruby amplifiers before entering the vacuum chamber. Nondestructive lasing in this mode requires an LTSG (Laser Triggered Spark Gap) which was also developed. The peak power is expected to be about 200 MW. Ordinary Q-switch lasing has been used to demonstrate ability to "plasmarize" falling 50-μ glass spheres. No spatial asymmetry has been observed for the 50-μ spheres in a 6 kG field, but the observed asymmetry of thin foil plasmas in the same

1. Controlled Thermonuclear Research Annual Report, Lawrence Livermore Laboratory Report UCRL-5002-70.

field underscores the necessity of using small pellets to achieve containment. In an attempt to manufacture small pellets of frozen deuterium, we have developed a special refrigerator by means of which a 50-μ-diameter thread of solid deuterium can be continously extruded into a rapidly pumped vacuum at a rate of a few cm per sec. The thread is to be chopped into small pellets which then must be focused, funneled, or at least collimated, so that they can serve as suitable target material in the experiment.

In July of this year we began a program of research aimed at producing a high-current, pulsed beam of neutral deuterium for injections into a mirror-machine experiment at Livermore. The goal is to deliver a 30-msec 10-A pulse of deuterium neutrals (atoms and molecules) at 20 keV into the target plasma formed in 2X II by trapping a plasma from a washer gun. The geometry of the experiment dictates a beam divergence of approximately ±1 deg. Since magnetic focusing of the ion beam before neutralization would result in a different focal point for each ion species in the beam (they differ in q/m) and consequently in loss of beam, and since beam energy modulation is easier if there is not a magnetic field to modulate, we decided to attempt an extractor design to generate an ion beam of small enough initial divergence that additional magnetic focusing would not be required. We also began the development of a plasma source of adequate size, uniformity, and density to permit extraction of a large ion beam, using multiple apertures, from which at least 10 A of neutrals could be produced by charge exchange and delivered to the mirror machine. The extractor design was carried out with the aid of a computer program. We constructed and tested a multiple-aperture extractor of this experimentally optimized extractor design. In general, the computed and measured extractor properties agreed very well. We have also designed and are constructing extractors utilizing arrays of slots in an attempt to prevent buckling of the structure when it is heated during the pulse. A novel large-area plasma source for the extractor has been developed.

Feedback-stabilization experiments on a plasma column ($n \sim 10^{13}$ cm^{-3}) in a magnetic field are approaching completion. Much of the work in the past year has centered on better identification of the low-frequency waves observed as potential and density fluctuations, and on development of pertinent theory. A prominent low-frequency ($f \approx 1$ to 7 kHz) fluctuation has been identified, in a fairly convincing way, as a Rayleigh-Taylor centrifugal flute, driven by the radial electric field. Feedback stabilization of this instability has been demonstrated.

Developments in theoretical work include the following:

(a) The nonlinear interaction of N oscillators, with N not too small ($N \sim 10$), is treated statistically. A diffusion equation for the probability density in action-space describes its evolution to a microcanonical distribution over that portion of the energy hyperplane for which the resonance widths (or relative-phase diffusivities) are nonvanishing. These widths are determined by nonlinear coupled equations, in terms of the resonance frequency-mismatches and the nonlinear interaction coefficients. For diffusion to occur, the interaction strengths must exceed the mismatches.

(b) As exemplified by the solar wind, an expanding plasma may become unstable with respect to infinitesimal Alfvén waves. The behavior of a finite-amplitude wave under these conditions was studied, using the Chew-Goldberger-Low model. It was found, first, that the stability criterion is amplitude-de-

pendent, and secondly, that the wave grows to such an amplitude as to modify the background into becoming stable with respect to it. For hyperalfvenic flow, an invariant is found, representing the specific wave energy flux in the plasma frame.

Several atomic and molecular collision processes were studied: dissociation cross sections for 0.5- to 1-MeV HeH^+ ions in H_2, He, N_2, and Ne gases have been measured; measurements of efficiencies of converting H_2^+ ions into $c^3\Pi_u$ hydrogen molecules in magnesium vapor, and of the relevant cross sections, neared completion; and measurements of collision cross sections of H_3^+ ions in H_2, Li, and N_2 gases have been completed.

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HEALTH PHYSICS

H. Wade Patterson in charge

RADIATION LEVELS IN AIRCRAFT

Roger Wallace

A series of measurements have been made to evaluate the radiation dose from cosmic rays received in commercial aircraft. The doses are about 5 mrem/round-trip flight of more than several thousand miles. When consideration is taken of the large number of passengers and crew who fly, this exposure of the genetic pool is second only to the exposure received from medical x rays and background radiation.

THERAPY WITH HEAVY-ION ACCELERATORS

Roger Wallace

The potential use of a high-energy heavy-ion accelerator for therapeutic treatment has been evaluated from the public health point of view. It is possible that such an accelerator could reduce the cost of radio therapy by half, and at the same time improve the results. The best ions to use are probably not heavier than neon. Energies up to 500 MeV per AMU (atomic mass unit) will be needed.

ICRP PUBLICATION 15

In 1967, the ICRP appointed a task group to revise Publication 3 (Protection Against X Rays Up to Energies of 3 MeV) and Publication 4 (Protection Against Electromagnetic Radiation Above 3 MeV and Electrons, Neutrons, and Protons), and to incorporate them into a single volume. The revision of the main text was published in 1970, and the appendix material is in preparation. The Health Physics Group has participated in this work,[1] particularly in supplying information relating to high-energy neutron dosimetry.

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(n, p) DIFFERENTIAL SCATTERING DATA

A. Rindi, T. Salmon-Cinotti (University of Bologna, Italy), and C. B. Lim

An empirical mathematical expression has been generated, using the least squares technique, for fitting the experimental data of the (n, p) elastic-scattering differential cross section from 20 up to 400 MeV.[1] This expression will be used in the unfolding programs for the neutron spectrometer.

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SPARK-CHAMBER NEUTRON SPECTROMETER

Alessandro Rindi and Chun Bin Lim

We are building an apparatus for measuring neutron spectra in the energy range from about 30 MeV to 300 MeV. It consists of a series of 12 spark chambers, each of them sandwiched between a triggering scintillator and a polyethylene sheet whose thickness de-

pends on the energy range to be covered. The protons generated by (n, p) elastic-scattering reactions with the hydrogen nuclei of the polyethylene converters and of the scintillators are detected by the spark chambers. We use chambers with magnetostrictive readout in which the coordinates of the sparks can be fitted directly into a computer program that evaluates the length and direction of the tracks. A second program unfolds the proton spectrum, calculating the corresponding neutron spectrum by either direct or iterative technique.

The apparatus is in the assembling phase. It will measure spectra of neutrons of an assumed angular distribution with an efficiency between 10^{-2} and 10^{-3} and an energy resolution of the order of 10%. It can be used for measuring stray neutrons around high-energy accelerators for protection or physical purposes, as well as spectra in scattered neutron beams.

NEUTRON MONITORING SYSTEM

Alessandro Rindi and the 184-Inch Crew

Six neutron-monitoring units (BF_3 moderated counters) have been connected through 100-ft cables to plug-in boxes located at different positions in the 184-Inch Synchrocyclotron building. The signals are sent to a Health Physics Monitoring Station in the building, to the Main Control Room, and to the telemetering line. This system allows for a complete monitoring of the experimental areas during the use of the accelerator.

SHIELDING STUDIES AT 28 GeV

R. H. Thomas (LBL); G. W. Bennet, H. Foelsche, D. Lazarus, G. Levine, W. H. Moore, T. Toohig (BNL); and J. Kostoulas (U. of Rochester)

The distribution of the nuclear cascade in steel has been investigated using ^{11}C-activation detectors. The high-intensity external proton beam of the Brookhaven AGS permitted studies to depths of 4.5 m in steel, greatly extending available data from previous experiments at CERN[1] and Berkeley.[2]

Studies were also made by coincidence counter techniques of the penetration of μ-mesons through steel to depths of 4.8 m. These measurements represent the most extensive μ-meson shielding studies made up to the present time.

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GROUND-WATER CONTAMINATION BY HIGH-ENERGY ACCELERATORS

Ralph H. Thomas

Studies of possible contamination of ground-water systems by high-energy accelerators, initiated at the Rutherford Laboratory,[1,2] have continued. A general evaluation shows it is unlikely that existing or projected high-energy accelerators in the energy region up to several hundred GeV pose a serious problem in this respect. Estimates of the production of radionuclides in the shield of the CPS,[3] based on neutron-flux measurements,[4] indicate that ^{3}H, ^{7}Be, ^{22}Na, ^{54}Mn, and ^{45}Ca are produced in the largest quantities in the earth and ground water. These data may be scaled to give the total quantity of radionuclides produced in the earth shield of a 500-GeV proton synchrotron. If mixing with the total inflow to the ground-water system due to rainfall is assumed, and if all the long-lived radionuclides are released,

maximum specific activities of $\sim 3 \times 10^{-2}$ MPC could arise in ground water. However, chemical sorption plays an extremely important role in limiting the release of radionuclides to the general environment. If only tritium is mobile, levels of $\sim 10^{-4}$ MPC are estimated.[5]

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2. G. B. Stapleton and R. H. Thomas, Estimation of the Ground-Water System in the Neighborhood of a Proposed 300-GeV High-Energy Accelerator Situated in a Chalk Site, Rutherford Laboratory Report RHEL/R, Dec. 1970.
3. F. E. Hoyer, Induced Radioactivity in the Earth Shielding on Top of High-Energy Particle Accelerators, CERN-68-42, Dec. 9, 1968.
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5. R. H. Thomas, Possible Contamination of Ground-Water System by High-Energy Proton Accelerators, Lawrence Radiation Laboratory Report UCRL-20131, Oct. 1970.

VAN ALLEN BELT RADIATION DAMAGE

Lloyd D. Stephens and A. Jerry Miller

A recently completed experimental research program investigated the extent of damage experienced by a spacecraft viewing port when exposed to a simulated Van Allen radiation field.

This work was carried out on a NASA-AEC contract and made use of the electron linear accelerator. Studies were also carried out to determine what damage, if any, would be experienced by the optical coatings on this glass at vacuums of approximately 10^{-9} Torr, and at both elevated and reduced ambient temperatures.

Additional work will be carried out to determine structural damage to the glass when exposed to protons having the energy spectrum and intensity equal to those in the South Atlantic anomaly of the Van Allen Radiation belt.

88-INCH CYCLOTRON RADIATION STUDY

Lloyd D. Stephens

A project has been started for cataloging the radiation areas and intensities at the 88-in. sector-focused cyclotron. The machine has the capability for acceleration of varied ions and energies; each of the possible conditions results in a rather unique radiation pattern and a catalog of these would be very useful for planning purposes.

A second project involves radiation-dose estimates to magnet structures associated with the machine. This is part of a larger study being carried out to determine the optimum material for potting magnet windings. Dose estimates are being made for the main magnet in the region of highest exposure. This will soon be completed.

TRACE-ELEMENT IDENTIFICATION

Alan R. Smith

We continue the use of high-resolution Ge(Li) semiconductor detector γ-ray spectroscopy in trace-element identification via reactor neutron irradiations. A pilot study of trace-element identification in several types of human tissue and blood (with Dr. T. Budinger, LBL Medical Department) has been completed; results are being prepared for publication. A preliminary study to identify air pollutants (with L. Hughes, UCB Radiological Safety Department) has resulted in a grant (to L. Hughes) for a specific full-scale study, under which the cooperative effort will be continued.

HIGH-ENERGY BEAM MONITORING

Joseph B. McCaslin and Alan R. Smith

Our high-energy beam monitoring techniques saw increased use this year by exper-

imental teams at both the 184-in. cyclotron and the Bevatron. We initiated an effort to verify the absolute accuracy of results obtained with the Au → ^{149}Tb reaction at Bevatron energies through direct comparison with the ^{12}C → ^{11}C reaction, for which more accurate cross-section data exist, but which (unlike the Au → ^{149}Tb reaction) is susceptible to interference from secondary particles. A similar effort is under way to improve the absolute accuracy of monitor results obtainable with the ^{12}C → ^{7}Be reaction, thus permitting precise measurements from much longer exposures than is possible with the ^{12}C → ^{11}C reaction.

Measurements have been made around the first three EPB magnets on the Bevatron's outside west platform in order to determine beam losses with the Piccioni extraction system. When the resonance-extraction system is in operation, these measurements will be repeated to make comparisons and to estimate radiation damage to the magnet components.

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NUCLEAR EMULSION GROUP

Harry H. Heckman in charge

The Nuclear Emulsion group engages in interrelated programs of research in the fields of cosmic rays, magnetospheric and high-energy physics. Technical programs include instrumentation for the analysis of particle tracks in nuclear emulsion, and, in cooperation with the University of California Space Sciences Laboratory, the development of solid-state (Si) particle identifiers for space and laboratory experiments.

Cosmic-ray heavy-ion physics is being pursued with nuclear-emulsion detectors that are part of a balloon-borne, superconducting magnetic spectrometer. This work is a cooperative effort with the Cosmic-Ray Division, NASA, Houston. The purpose of the work is to determine the momentum and charge spectra of the heavy cosmic-ray primaries for rigidities (=pc/z) up to about 250 GV, and to study their interactions in matter.

Experimental and theoretical work on the spatial and temporal properties of high-energy ($30 < E < 600$ MeV), geomagnetically-trapped, inner-belt protons continues to be a major effort of the group.

We have also been involved in the development of a new method for increasing the sensitivity of plastic track detectors, and in a study of accelerator irradiations of minerals.

VARIATIONS OF INNER-ZONE PROTONS

Harry H. Heckman and Peter J. Lindstrom

As described in the previous issue of this report, we have undertaken a theoretical analysis of our experimental data on the time variations in the flux of low-altitude, energetic ($E > 57$ MeV), geomagnetically-trapped protons. The data are being interpreted in terms of a time-dependent continuity equation.

The results of this analysis are able to account for the main features of the data, such as the 3 1/2-yr "steady-state" period following the July 1962 Starfish detonation, and the changes in the flux owing to solar-cycle changes in the atmosphere before and after Starfish (Fig. 1).

We examined the possibility of observing effects of semiannual changes in the atmo-

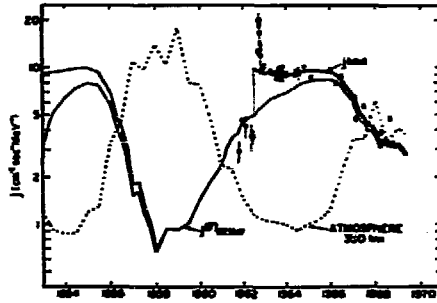

Fig. 1. Computed proton flux $j(t)_{60\ MeV}$ at h_{min} = 350 km, beginning 1953.0, assuming source S_{obs} is constant, and initial flux values $j(1953) = 9.2$ and $3.2\ cm^{-2}\ sec^{-1}\ MeV^{-1}$. Unique solution is obtained at this altitude after 1958.5. The Starfish redistribution on 9 July 1962, the 3-yr "steady-state" from 1963 to 1966, and the abrupt solar-cycle decrease in the proton flux after mid-1966 are reproduced in these calculations. The data denoted by open circles are from work by Fils and Holeman; the x's, this experiment. The data points are limited to $h_{min} = 350 \pm 50$ km. Solar-cycle behavior of atmosphere at 350 km altitude is given by the dashed curve. (XBL-6910-5954)

spheric density of particle fluxes for altitudes < 320 km. We conclude such changes should be observable; however, an undesired phase difference appeared between the observed and computed semiannual effects. We are now attempting to resolve this problem by incorporating into our computations an improved model of a diurnally averaged atmosphere--one that incorporates changes in density and composition as a function of altitude, solar activity, semiannual effect, and solar angle (seasonal latitude effect). The subroutine to incorporate this atmospheric model into the theory is near completion. Preliminary estimates have shown that the revised atmospheric model will predict semiannual changes [illegible] with our observations.

GEOMAGNETICALLY TRAPPED PARTICLES

Harry E. Bachman and Douglas S. Greiner

Two rocket-borne experiments were successfully performed in September 1970 at Natal, Brazil. The flight instruments were multidirectional, solid-state telescopes that consisted of eight 2-cm^2 lithium-drifted silicon detectors. Detectors 3 and 8 were 2-mm thick; 2 through 7 were 5-mm thick. The telescopes measured protons with an energy range of 15 to 150 MeV. Pulse-height information from each detector was also obtained in the range of about 0.4 MeV.

[illegible] rocket [illegible] absolute [illegible] less than [illegible] the mass [illegible] is less was ±50 MeV, independent of particle mass. This implies mass resolutions of at least 1:10 between isotopes. (See Fig. 2.)

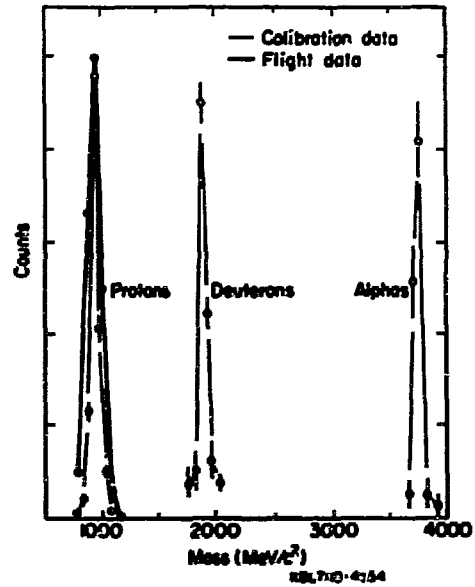

Fig. 2. Mass resolution of the particle identifier used in the high-altitude rocket experiments.

The analysis of the flight data is progressing satisfactorily. The trapped-proton mass-distribution has a σ of 66 MeV, slightly greater than that obtained with unidirectional beams in the laboratory. To date, we have obtained results on the equatorial pitch-angle distribution of the trapped protons, their east-west asymmetries, spectra 30 < E < 70 MeV for trapped and untrapped particles, and preliminary estimates of the abundances of trapped deuterons (0.5% based on 11 events) and tritons (0.09% based on 1 event).

This work is supported in part by the National Aeronautics and Space Administration.

RIGIDITY SPECTRA OF HEAVY IONS

Robert L. Golden (Manned Spacecraft Center, NASA, Houston); and Harry H. Heckman

During October-November 1970, two balloon flights totaling about 18 hr flight time were successfully carried out at Parana, Argentina, where the cosmic-ray rigidity cut-off is 11 GV. As in the balloon experiments carried out in August 1969, heavy-ion rigidities are measured by using emulsion plates exposed in a magnetic field supplied by a 10-kG superconducting magnet. All emulsions from these flights have been developed. Analysis of these data will begin as soon as the scanning of the August 1969 flight emulsions is completed. At this time, we are in the process of re-scanning the emulsions for efficiency checks. From this experiment, we expect to have up to 700 heavy ions measured as to rigidity and charge.

MAGNETIC BREMSSTRAHLUNG

M. Mashkour (Illinois Institute of Technology); and Harry H. Heckman

A joint experiment between IIT, SLAC, and LBL was undertaken to study the characteristic bremsstrahlung radiation emitted by 19-GeV electrons in megagauss magnetic fields. In this experiment, the MG fields were generated in volumes ~ 1 cm^3 by capacitory discharge in single-turn coils.[1] Useful lifetimes of the fields were ~ 1 μsec. The energy and angular distribution of the bremsstrahlung are being measured by detecting the e^+e^- pairs produced in nuclear emulsions by the emitted radiation.

Evaluation of the emulsion detectors used in this experiment has just begun. Progress made to date involves: evaluation of the signal and background distributions of pairs in the plates, and preparation of programs to aid in data collection and in evaluation of pair-energies from multiple-scattering measurements. We expect to undertake routine data collection shortly.

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Computing and Data Handling

MATHEMATICS AND COMPUTING

James A. Baker in charge

The Mathematics and Computing Group provides advanced computing services to the Laboratory's research and support groups. These services include installing and operating the Laboratory's central computing facility, which consists of a new CDC-7600/6215 computer complex, two multiprogrammed CDC-6600's, several smaller IBM computers, and associated peripheral equipment and instrumentation. Large data files are maintained in machine-readable form. The Systems Programming staff develops, maintains, and modifies the software for these computers, while the Application Programming staff provides programming support to the many Laboratory physicists and other researchers who use computers for data collection and analysis. The Group offers consultation services in mathematics, statistics, and programming; and also carries on a modest program of research in mathematics and computer science. Increasingly, these services are being provided to scientific groups outside the Laboratory.

APPLICATIONS PROGRAMMING

A major effort was initiated to convert existing applications programs and library routines to run on the 7600 computer. In addition, applications programming personnel provided programming support for most of the research groups at the Laboratory.

Physics

Herbert C. Albrecht, Donald Austin, Emmett Burns, Victor Elischer, Fred C. Gey, Art Habegger, Edna Williams

Physics Group R is currently conducting two experiments at the 184-in. cyclotron: a spark-chamber experiment located in the West Counting Area to study radiative pion capture, and an experiment in the East Counting Area to study positive muon depolarization. Both are controlled by an 8K memory PDP-15 computer.

The spark chamber experiment has been operating on a part-time basis for the last nine months. During this period the experimenters discovered some problems in the large wire chambers. These have recently been rebuilt, and the experiment is now running on a regular basis, for at least the next year.

The muon experiment was tied into the PDP-15 about four months ago, and has been taking data for approximately two months. Because this experiment requires a large fast data base for its main histogram and because it is desirable to monitor this histogram during the course of the run, the experiment provided the impetus for an expansion of the PDP-15 to a memory of 16K. The data-acquisition programs for this experiment have already been modified to operate in 16K. We also modified all the Physics Operating Systems Programs since they are required to support the Muon program. We still have to modify the Pion program and expand its monitoring capabilities to utilize the extra core.

The VARMIT-based data-fitting routines used by Physics Group R were modified to give more reasonable and reliable results. Also,

autocorrelation and Fourier transform routines were developed for analysis of the Group's data. These are now in regular use since they proved very successful in obtaining an accurate analysis of the data content. Both programs have been converted to run on the 7600 system.

Programming support was provided throughout the year on ACQUIRE to do the data acquisition for the $^3He + \gamma$ time-reversal experiment. Specific processes in the data acquisition were identified and separated into subroutines in preparation for a general data-acquisition system for wire chamber particle-physics experiments. Final track-finding procedures were programmed and incorporated into the data-summary program. A procedure for measuring chamber-wand efficiencies was developed and put into the program.

The SPARKY data-acquisition program for wire-chamber experiments is nearly finished. Only a few programming touches and a mammoth documentation effort remains.

For the π^0 form-factor experiment, we have provided occasional data-analysis programming aid, in particular, in the generation of the three-dimensional magnetic field.

Other physics-oriented projects have included: development of a data processing and analysis system for the SPEAR project at SLAC; development of a new bubble-chamber event-sorting program; additions and modifications to COBWEB, a computer-controlled data-acquisition system; and modifications to existing production codes to accommodate new experiments.

Accelerator and Magnet Design

Victor Brady, Bruce Burkhart, Thomas Clements, Elan Close, John Colonias, Robert Healy, Ardith Kenney, Arthur C. Paul, Steven Sackett

Mathematical models describing components of the Electron Ring Accelerator have been constructed. With these models the dynamics of compressors were studied, including the effects of eddy currents; and the results obtained were used in developing a new design incorporating resistive coils and simpler switching circuits. A program BUNCH was created to investigate the impedance of an azimuthally bunched beam in a cylindrically symmetric structure.

For the Bevalac project, the Bevatron injection process was simulated by computer programs. The calculations were verified by comparison with measurements on the existing 19.3-MeV linear injector. The performance and optimum parameters of the new 50-MeV injector were then predicted.

The profile and other properties of the main and satellite beams of the 184-in. cyclotron were computed and found to agree reasonably well with observations.

Computer studies showed that second-order aberrations affected the pion contamination of the K^- beam at the Bevatron, and led to improvements in the K/π ratio of the beam.

Programs were contrived to optimize the phase-space transmission of the focussing magnet in the source for the Baseball II CTR experiment at the Livermore Laboratory.

The three-dimensional magnet design code is now at the stage where simple geometric configurations can be handled. Work continues to speed convergence and to allow more complicated geometry.

Work was started on the solution of the wave equation with prescribed sources given by an assumed azimuthal modulation in electron beam intensity.

And finally, in the field of environmental studies, we have developed the program OZONE to study the effect on atmospheric ozone of varying such parameters as nitrogen oxide production rate, solar angle, temperature, reaction

rates, etc. This work grew out of the widely publicized prediction of Harold Johnston of IMRD that supersonic transport traffic would deplete the atmosphere of ozone.

Nuclear Chemistry

Billie Bearden, Noel Brown, Emmett Burns, M. L. Clinnick, Penny Fink, Ruth Hinkins, Gerald Litton, Tom Strong

Development of computer-based control and data-acquisition systems for the Superhilac was started this year. The PDP-7 pulse-height analysis system was improved and is now capable of collecting data from up to 128000 channels. Work started on a PDP-15 data-collection system.

Modifications were made to the small computer system at the Field Free Laboratory. The system now permits preliminary analysis of the data before final processing on the 7600.

We have completed version 1.0 of the CHEM-SCROLL text input and editing system, which will be used in preparing a new edition of the Table of Isotopes.

For the fission group, we have written a program that will sort californium-252 fission fragments. The unstable fragment nuclei are identified from gamma-ray energy peaks.

In analytical chemistry, digitized normalization of controlled-potential coulometric titrations are being done with a 6600 program. A set of routines is being developed to analyze spectra obtained from anodic stripping measurements. With the aid of these routines, impurity concentrations on the order of a few parts per billion will be recognizable.

Work on theoretical models of the nucleus and nuclear structure continues. An interactive VISTA and teletype program was developed to fit nuclear masses to a Droplet Model formula. After nonlinear least-squares fit to the nuclear masses is made, experimental and computed values of nuclear radii and fission barriers can be examined. The stability of nuclei against fission was computed using the Droplet Model. And several codes were written to compute average nuclear properties using the Thomas-Fermi statistical model.

Modifications were made in a set of programs which calculate electrostatic, spin orbit, and crystal field matrix elements, and which then diagonalize the matrices, simultaneously handling these perturbations to the central field approximation.

The determination of optical model parameters, used to describe the nuclear elastic scattering process, has been aided by the development of an on-line VISTA program. This program allows the visual display of angular distributions calculated using parameter values chosen by the researcher.

A study of the (d,p) reaction on vibrational nuclei was completed. This was accomplished by the solution of two sets of coupled differential equations which describe the nuclear states obtained in the scattering process. The final program SCATER was used to study several systems. The scattering of heavy nuclei was studied using a modified version of SCATER. Cross sections for various states were calculated and studied.

Biology and Medicine

Robert Belshe, Victor Eliscber, Robert L. Fink, Fred C. Gey, William Hogan, Harvard Holmes, Mark W. Horovitz, Martin S. Itkowitz, Claudette Lederer, Marjory Simmons, Kenneth G. Wiley

Work was completed this year on five different data-acquisition systems:

(1) A PDP-8 with Data Disc for NMR spectroscopy at the Laboratory of Chemical Biodynamics.

(2) A PDP-12 system for blood flow studies at Donner Laboratory.

(3) Program PHA, running on a PDP-8/I, for cell volume measurements at Donner Laboratory.

(4) A data collection, computation, storage, and retrieval program for Donner Laboratory. This program runs on a PDP-8/L with the AX08 option. The data are taken from an EPR spectrometer and displayed in real time. The operator can manipulate the spectra in many ways: scaling, subtracting out backgrounds, and integrating. These spectra are stored and retrieved on magnetic tape cassettes.

(5) A program designed to analyze particle telescope events. Running on a PDP-8 at the Bevatron, the program does a least-squares fit of the data to a theoretical event. The primary purpose of the program is to identify isotopes entering the particle telescope. It is used during system checkout to verify that the equipment is working correctly.

Development continued on programs for ISAH, a computer-controlled patient chair for use in radiation therapy.

Improvements were made to MIMIC, a program that simulates an analog computer.

Program RATS was written to trace, using compartmental analysis, radioactive tracer progression and decay in rat vital organs. A study (program TEETH) was made modeling the retention of radioactive tracer in rat teeth.

A set of programs for processing digitized images was completed. TBSYS, a set of 6600 programs, performs sequences of transformations upon given $(2^m \times 2^n)$ arrays Z of complex numbers representing two-dimensional digitized images generated by some device such as a scintillation camera, whole-body scanner, EEG recorder, x-ray detector, or electron microscope. Graphic displays of the surface $Z \cdot Z^*$ are available at any point in the sequence of transformations. The central transformation utilizes the two-dimensional Fast Fourier Transform E2 BKY TDFFT, which also determines the file configuration for Z. Related transformations are (1) variable annular mask to effect low-or high-pass filtering, (2) 90° phase rotation, (3) phase modulation transfer function applied in the frequency domain, and (4) conversion to intensity. Three types of display of the surface $Z \cdot Z^*$ are available on 35 mm film or Calcomp plot: perspective projections, contour maps, or cross-sectional views (profiles).

In order to identify the radioisotopes present in materials in a number of experimental situations, analyses are made of fairly complex gamma-ray spectra produced in a high-resolution germanium gamma-ray spectrometer.

The isotope identification program GOLUX is designed to automate the look-up procedures involved in verifying the existence of a particular radioisotope from these gamma-ray spectra, which may contain 50 to 200 energy peaks each. At present, GOLUX contains programs to compile and random-access a library of known radioisotopes, their half lives, their gamma rays, and some other properties; it can make and update a "quick-look-up" table of gamma rays, cross referenced to isotope and half life. It also contains a retrieval subroutine for gammas of a given energy.

These isotope identification problems turn up in connection with:

(1) looking for trace elements in air-pollution studies;

(2) analyzing materials that have been bombarded by high-energy particles in an accelerator, either accidentally or on purpose;

(3) analyzing unexplained activity in and around accelerators;

(4) diagnosing the type of exposure in human radiation accidents;

(5) examining biological materials--blood and tissue--to determine normal and abnormal concentrations of trace elements in order to use

this information as a future diagnostic tool.

ACQUIRE, a data-acquisition system at the Laboratory of Chemical Biodynamics, utilizes a Sigma-2 and a PDP-8/L computer. During the past year, all equipment became operational except the actual interfaces to experimental devices, which are now being built. Remote use of teletypes and displays became available, as well as numerous FORTRAN and BASIC applications programs. The CDC-6600 program FELSPAR, used for fitting photoelectron spectra, was improved and rewritten under the name GAMET. A BASIC language compiler was written and completed, and a tape library system was developed. An ACQUIRE user's manual was published.

General and Engineering

Donald Austin, M. L. Clinnick, Harvard Holmes, Mark W. Horovitz, David W. Jenson, James G. Miller, Leo Vardas

An extended version of the BLIMP language compiler has been completed for the 6600/7600 system. This code is being used to implement some Management Information Systems designs.

A program PCBOARD was written for computer-aided design and layout of printed circuit boards. This VISTA console program can produce microfilm output suitable for direct masking of prototype boards.

A general purpose graphical input modeling program PICASSO was started. It enables a user to construct and define symbols at a VISTA console. Structures containing these symbols can then be specified and converted into a form suitable for input to analysis programs. For example, logic circuit diagrams could be designed at the console, and the behavior of the specified circuit could be immediately analyzed using the MIMIC simulation program.

The Cagniard method of sound-wave analysis was studied, programmed, and debugged (CDC-6600 FORTRAN program CAGN). Applications include seismic-wave studies and ultrasonic testing problems.

A device handler on the PDP-9 and a code on the CDC-6600 were written and debugged to allow file transfers between the machines via the Data Link.

The Remote Computer Access System (RCAS) for connecting remote computers into the 6600 complex was defined, written, and debugged.

CRYSTAL, a computer model for the statistical treatment of dislocation motion through a crystalline structure containing randomly distributed obstacles was developed. The program is being used to generate data for the statistical model of dislocation motion developed by Professor John Dorn and Dale Klein of IMRD. A ten-minute computer-generated movie was made demonstrating the model. The movie was presented with a review paper at this year's Symposium on Statistical and Probabilistic Problems in Metallurgy in Seattle.

A data-collection program was designed and partially implemented for infrared spectroscopy for Paul Richards of IMRD. Running on a PDP-11 the program samples data from a Michelson interferometer and stores it. The program also computes a real time Fourier transform of the data being taken and displays it on a storage scope.

SYSTEMS PROGRAMMING

6600 System

A number of modifications to the system were installed with the object of utilizing the 64-control-point system more effectively; chief among these were an "auto-roll" feature (which causes jobs that are waiting for operator action to release all assigned core, either

outright or via roll-out to the disk); an automatic field-length assignment for system utility job-steps; and an automatic system for paging tapes out of the tape library.

A new, less quixotic, accounting algorithm was introduced, based upon CPU time, monitor requests, and instantaneous field-length. The new algorithm is relatively independent of system loading, whereas the former algorithm, which used PPU time to measure I/O activity, was extremely sensitive to I/O conflicts.

The System was also modified to run on computers having different memory sizes and either 10 or 20 PPU's; this will allow the same BKY system to run on the 6215 front-end computer as well as on the 6600's.

A dynamic buffering scheme to provide more efficient utilization of rotating mass-storage devices was designed and should be ready for installation in the first quarter of FY 1972.

7600/6215 System

The 7600/6215 computer complex was delivered and accepted during the fourth quarter of FY 1971. The 7600 initially used CDC's standard SCOPE 1.1 System, while the 6215 was accepted using the BKY system originally developed for the 6600's.

Interactive Systems

RECC (the new teletype interface) was installed and connected to both 6600's; in the fourth quarter of FY 1971, it was upgraded to a PDP-8/E with a 28K memory (instead of a PDP-8/L with an 8K memory). BRF was modified to accept RECC teletypes as well as teletypes connected through the 6411. PTSS, a modest time-sharing system with extensive symbolic debugging capabilities, was introduced to general use in the first quarter of FY 1971; it was developed jointly by members of our Systems staff and a member of the University of California Space Sciences Laboratory.

Remote Batch

A survey of prospective remote batch users revealed a much greater interest than had been anticipated. As a result, the remote batch pilot project was diverted into another channel (local on-line small-computer access), and a commercial remote batch system was sought. A COPE system was selected and installated on both the 6600A and the 6215 in the fourth quarter of FY 1971.

COM (Computer Output to Microfilm)

A Stromberg-Datagraphix Computer Output to Microfilm System with graphic capabilities was delivered in the fourth quarter of FY 1971; it is expected that it will be the principal output device for the 7600.

COMPUTER OPERATIONS

Design and construction work for the installation of the CDC-7600 was completed in the fourth quarter of FY 1971. Also, the Input/Output and Noisy Ready Rooms were redone to allow room for customer card readers and printers. A small addition to Building 50B was designed and constructed in order to house electrical equipment to provide power to the 7600 computer. The computer was delivered and installed during the fourth quarter, with power-on accomplished in April.

An automated tape-paging system for the 6600 system was implemented, resulting in faster, more accurate customer service with

reduced operations manpower.

A scheme for producing detailed error data from magnetic tape input/output software allowed greatly improved diagnosis and repair of hardware malfunctions in tape drives and controllers.

A program for upgrading the magnetic tape density to 3200 FCI was commenced with the installation of a CDC-686 Tape Certifier.

USER SERVICES GROUP

Due to the increased use of computer facilities by offsite personnel, it became desirable to centralize our user services. Therefore, in the first quarter of FY 1971, a User Services Group was established to coordinate consultation, training, documentation, and the Mathematics and Computing Library. In addition, to centralization of these services, the function of the User Services Group is to act as the interface between the Mathematics and Computing Group and the computer user.

The consultation service has been extended to provide programming assistance during evening hours and on Saturday. Expansion of the training program includes offsite demonstrations of the use of our remote computing facilities. Clear, current documentation of systems and library routines--provided by the addition of a technical writer--has aided the user immensely.

MATHEMATICS AND COMPUTING RESEARCH

Donald Austin, James Baker, Paul Concus, David Jenson, Loren Meissner, Grove Nooney, Leo Vardas, Jonathan Young

Our research in applied mathematics is directed toward the development of numerical techniques for the solution of partial and ordinary differential equations and toward the automation of certain areas of numerical analysis. Research in computer science is in the areas of symbol manipulation, development of scheduling algorithms for multiprogram computer systems, and the development of optimal man-machine interfaces.

Partial Differential Equations

Investigation of the partial differential equation describing the equilibrium free surface of a liquid partially filling a cylindrical container was continued with emphasis on completing the establishment of general existence criteria. Means for obtaining the numerical solution of the equation were investigated.

Ordinary Differential Equations

The tools developed in prior years (analytic generator of Runge-Kutta methods and generalized integrator) were used in the investigation of a number of specific examples of generalized integration schemes, including various step-size adjustment strategies and starting procedures.

Technical Text Editing

Output facilities were improved, including installation of an Alden facsimile recorder connected to the small computer that controls the technical text entry station. A file can be printed by means of this device as soon as it has been generated, at the rate of 1400 characters per second. This provides immediate hard-copy output for proofreading purposes.

An extended character set based on a 9×12 dot matrix was developed for use on the facsimile recorder as well as on the 6400 VISTA-CRT microfilm output system. This set contains about 240 characters, including upper and lower case Greek and Roman alphabets, two styles of number, linguistic accents,

and many mathematical symbols. About 40 of these characters are to be left unstandardized, and a reasonably simple means is provided whereby any user can redefine any or all of these 40 characters to suit his particular needs.

A line-oriented editing algorithm was implemented as an alternative to previous character-oriented and page-oriented systems. The user can select whichever one of these editing algorithms seems most appropriate for his needs.

A system for automatic overlay of program segments from disk was implemented on the computer that controls the text editor. This permits extension of program storage space, which is necessary for incorporating the complex editing logic required for entry of Isotope Table data.

Biological Applications

Investigation was continued of the connection between the increased risk of leukemia following pregnancy in middle age and the known increased risk of leukemia in the issue of such pregnancy. A dynamic mathematical model for control of proliferation and release of blood cells and their precursors was devised. The model includes age-dependent processes and is suitable for simulation of stress on the leukopoietic and neutropoietic series.

Seismology

In the implementation of the Cagniard method for the calculation of seismic waves propagating in various media, a numerical analysis was done which accommodates singularities in the reflection and reflection coefficients and which permits source definition by direct-wave measurements.

High-Energy Physics

Continuation of previous work with W. Rarita on Regge-pole fits to high-energy pp and $\bar{p}p$ data resulted in a paper predicting the slope of the pp differential cross section out to a laboratory momentum of 2000 GeV/c. Subsequent measurement of this slope parameter at the CERN ISR produced data in excellent agreement with our predictions.

Artificial Intelligence

In collaboration with Dave Jensen, the PDP 8/I was rigged to collect voice data from a telephone receiver input. A "learning machine" was written to recognize the voice patterns. The initial effort was a binary pattern recognition program which distinguished between two input words with a 99% success rate, after reducing the input from 8000 samples to about 50.

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DATA HANDLING

Howard S. White in charge

The Data-Handling Group is involved in designing specialized systems for scanning, measuring, and analyzing experimental data from bubble chambers used in high-energy particle-physics applications; in improving the effectiveness of computer programming in areas related to high-volume precision analysis systems; and in operating data systems in support of experimental physics research.

DAPR: AUTOMATIC SCANNING AND MEASURING OF BUBBLE CHAMBER EVENTS

Barbara Britton, Joan Franz, Wen-Sue Gee, Dennis Hall, Howard White

During this year, the Digital Automatic Pattern Recognition (DAPR) system was first used to measure a substantial volume of data. This system uses the same IBM-7094 II computer and Flying Spot Digitizer (FSD) as the HAZE system which it will gradually replace. DAPR, unlike HAZE, is able without manual assistance to perform the entire scanning, measuring, and analysis of bubble-chamber events. The DAPR process forms on magnetic tape a digitial abstraction of information contained in bubble-chamber film, from which a digital computer program "scans" and edits measurements for subsequent analysis. Although DAPR operates without manual assistance, prescanning to give frame selection of those bubble-chamber pictures containing events is economically advantageous when the ratio of frames to events exceeds three; this frame preselection has been used on film measured this year. More than 338 000 events have been measured in the DAPR mode during the year.

A second FSD unit is being fabricated to form a Tandem FSD system, which will nearly double the present measurement capacity, now that DAPR has removed the "bottleneck" of manual road guidance.

In preparation for an experiment in the SLAC 82-in. chamber for the Trilling-Goldhaber Group, a completely new procedure for resolving conflicting hypotheses is being developed in the vertex finding-track matching program. This procedure is expected to raise the throughput of the DAPR system to above 90%, and should be operational within the first half of FY 1972.

With the goal of totally unassisted analysis of bubble-chamber data now firmly established, it seems but a small step to explore two new areas: (1) Streamer chamber pictures have already been digitized by the FSD. Adaptation of the software appears straightforward. Thus, the same speed and precision of measurement previously available only to bubble-chamber experimenters could easily be made available to streamer-chamber experimenters as well. (2) Somewhat more difficult, but also feasible, is the automatic processing of film from large bubble chambers of the 14-ft class. The ability of the FSD to digitize such pictures has been established. Modification to the track-following and track-linking software to accomodate these pictures seems straightforward. Success in this area will open up a new vista in large statistics analysis of complex event types.

HAZE: SEMIAUTOMATIC MEASUREMENT

Wen-Sue Gee, James Greene, Carol Osborne, Priscilla David

The HAZE measurement system continued to be used for experiments begun before DAPR became operational. First used for physics measurements in FY 1964, HAZE utilizes a large digital computer, operating the FSD and related computer programs, to automatically measure film in which manual scanning has previously identified tracks and events of interest. More than 2 300 000 events have been analyzed by this system, including about 200 000 this year. System improvements were limited to the many small adjustments required to maintain processing of continuing physics experiments.

FCF: GEOMETRY, KINEMATICS, DISPLAY

Michael Block, Shirley Buckman, Vivian Morgan, Loren Shals

The FOG, CLOUDY, and FAIR system, which provides the analysis of bubble-chamber events, continued routine production operations. The major portion of FCF effort was expended on generating new experiment-dependent constants and new event types.

New optical constants and a new magnetic-field subroutine were developed for the SLAC 40-in. chamber. Preparation for the new 35-mm, 82-in. chamber film will begin in early summer.

A low-priority effort to improve the processing rate of the geometry program was undertaken. This program now consumes nearly half of the event analysis time, but significant speedup appears possible. An improvement in this area will have a major effect on the cost of analyzing events.

Work on obtaining clean assemblies of all FCF programs concluded with the achievement of these goals during July 1971.

TRIST: SYSTEMS MONITOR

Priscilla Davis, Carol Osborne

Most of the effort on the TRIST system monitor was expended in making the many small changes required to smooth out operations during the simultaneous operation of all three program priority levels. Considerable experience was gained because of the continuing operation of DAPR.

The need for more core storage to implement needed improvements has been a serious problem for the system monitor. A new assembly was written and partially debugged which will free a considerable portion of the core within the system areas, by storing relatively inactive subroutines on the disk and recalling them only when they are needed.

Due to an elusive electronics failure, the A-level program (HAZE or DAPR) occasionally lost contact with the FSD. This condition was often not detected by the operating personnel for many minutes. As a result, a significant drop in the measuring rate was observed. The existing system monitor was modified to watch for this condition. If no information was transferred from the FSD for more than 30 seconds, the A-level program was automatically reentered. This produced the desired result of bringing the measurement rate back to its nominal value eve... the presence of a very low-frequency, hardware malfunction.

Work on the time-accounting program was completed. This program summarizes, on a daily basis, the distribution of jobs, the amount of lost time, and the efficiency of computer operations. With it, supervisory personnel can be more effective in monitoring performance as well as in planning the next day's work load.

DATA-PROCESSING OPERATIONS

The following table summarizes the processing of events measured on the COBWEB, HAZE, and DAPR systems. An event is the entire collection of related vertices measured in a bubble-chamber picture. New measurements of the same event are counted separately, but the effect of any computer reprocessing has been eliminated from the totals.

EVENT MEASUREMENTS ANALYZED
(FY 1971)

COBWEB SYSTEM

Experiment	Chamber	Beam	Group	Number of events
42	72" HBC-LBL	1.3-1.6 GeV/c π^+	Powell-Birge	148
43	72" HBC-LBL	1.3-1.6 GeV/c π^+	Powell-Birge	212
44	72" HBC-LBL	1.3-1.6 GeV/c π^+	Powell-Birge	131
45	25" HBC-LBL	1.53-1.84 GeV/c π^+p	Powell-Birge	457
47	25" HBC-LBL	1.53-1.84 GeV/c π^+p	Powell-Birge	1 657
50	25" HBC-LBL	1.53-1.84 GeV/c π^+p	Powell-Birge	1 415
51	25" HBC-LBL	1.16-1.57 GeV/c K^-	Powell-Birge	8 122
52	25" HBC-LBL	1.16-1.57 GeV/c K^-	Powell-Birge	3 610
55	25" HBC-LBL	1.16-1.57 GeV/c K^-	Powell-Birge	8 071
66	82" DBC-SLAC	5 GeV/c γ	Powell-Birge	148
67	40" HBC-SLAC	14 GeV/c π^-p	Powell-Birge	3 353
			Total COBWEB Measurements	27 324

HAZE SYSTEM

Experiment	Chamber	Beam	Group	Number of events
01	82" DBC-SLAC	12.0 GeV/c π^-	U. C. Riverside	59 527
45	25" HBC-LBL	1.53-1.84 GeV/c π^+p	Powell-Birge	2 521
53	25" HBC-LBL	1.16-1.57 GeV/c π^+p	Powell-Birge	7 509
57	25" HBC-LBL	1.56 GeV/c π^+p	Powell-Birge	16 224
71	72" DBC-LBL	6.0 GeV/c p	Segre-Chamberlain	107
72	80" DBC-BNL	8.0 GeV/c p	Segre-Chamberlain	1 160
95	82" DBC-SLAC	12.0 GeV/c K^+	Trilling-Goldhaber	104 808
			Total HAZE Measurements	191 855

DAPR SYSTEM

Experiment	Chamber	Beam	Group	Number of events
58	25" HBC-LBL	2.9 GeV/c π^+p	Powell-Birge	82 860
59	25" HBC-LBL	2.3 GeV/c π^+p	Powell-Birge	62 345
60	25" HBC-LBL	2.1 GeV/c π^+p	Powell-Birge	32 211
61	25" HBC-LBL	1.28 GeV/c π^+p	Powell-Birge	21 726
62	25" HBC-LBL	1.28 GeV/c π^+p	Powell-Birge	21 274
63	25" HBC-LBL	1.81 GeV/c π^+p	Powell-Birge	65 782
64	25" HBC-LBL	1.18 GeV/c π^+p	Powell-Birge	51 881
			Total DAPR Measurements	338 084
			Total Events Analyzed	557 264

FSD MONITOR

Loren Shals

The problem of observing stage stability during acceleration and deceleration was difficult in the past, due to an interlock system which inhibited digitizing during these critical phases. Hardware changes were installed which allow the program to override this interlock and thus to sample stage-speed for the entire sweep. A display of the stage velocity as a function of stage position is now run on a daily basis as a check of the servo system. This has allowed early detection of servo malfunction, with the result that repair costs were kept to a minimum. The problem of checking for drift in the fixed stage was also studied, but a completely satisfactory solution has not yet been found.

QUARKS

Shirley Buckman

Processing of Quark data continued steadily. By the end of June 1971, 34150 cloud chamber tracks had been processed. Because the chamber optics are not stable for periods longer than a few hours, each batch of data must have its optical constants verified before processing can occur. Procedures to accomplish this have now been refined to the point that a batch of one hundred tracks is typically processed within three to five days of their measurement, using perhaps five minutes of computer time. No further procedural or programming changes are anticipated for this experiment, which is scheduled for completion in July 1971.

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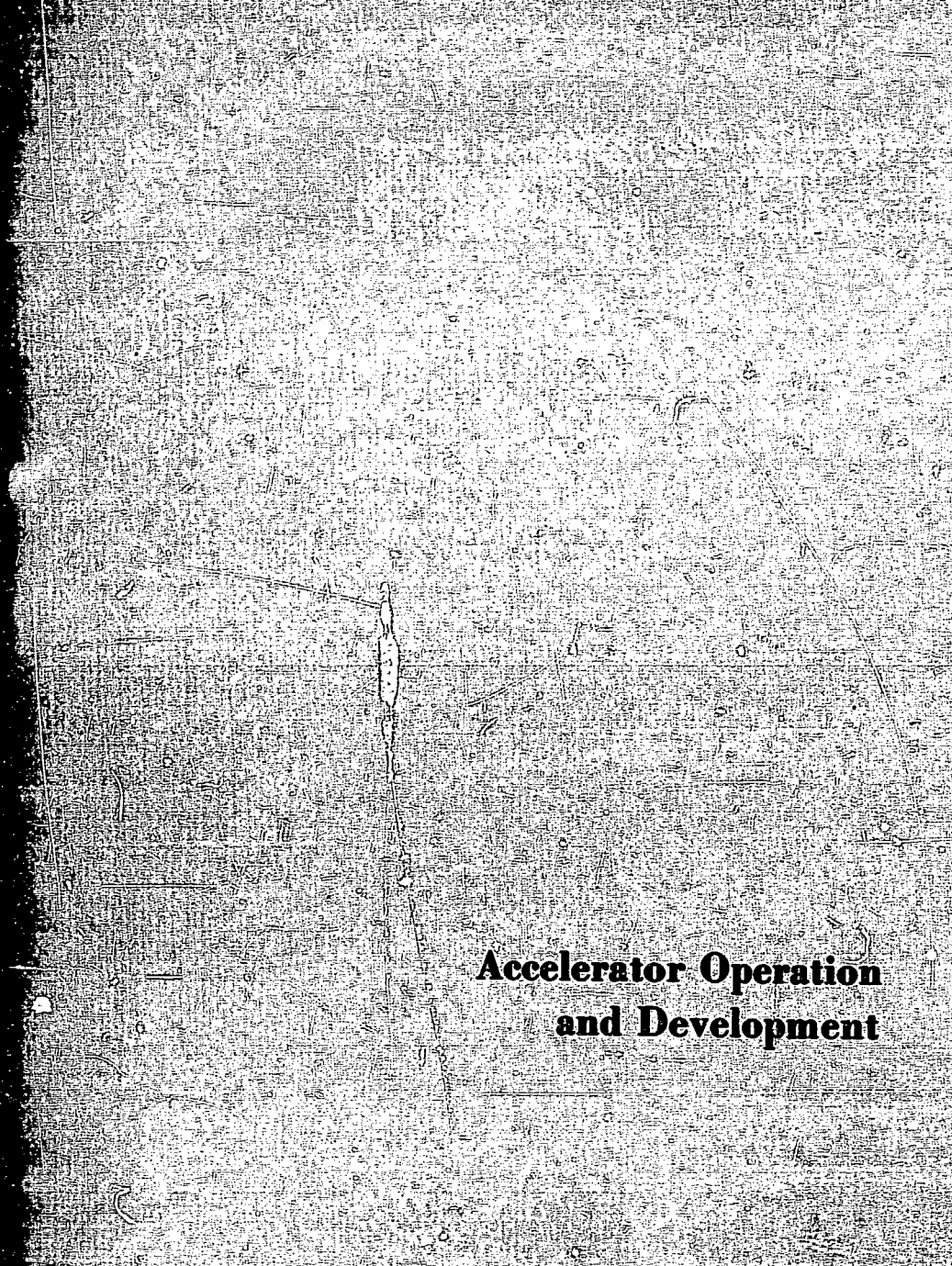

Accelerator Operation and Development

ACCELERATOR STUDY GROUP

Edward J. Lofgren in charge

ELECTRON RING ACCELERATOR

Further research into the new method of accelerating protons and other positive ions by means of electron rings is being actively pursued by the Advanced Development Group. The principle of the electron-ring accelerator (ERA) involves the use of a dense ring of relativistic electrons that forms a stable vehicle for the acceleration of protons or ions imbedded in the ring. Because of their small mass, the electrons accelerate rapidly in an externally applied field, and the heavier but less numerous ions are carried along with identical acceleration but much greater energy gain because of their heavier mass. In this way, equivalent electric accelerating fields for ions of millions of volts per centimeter can be achieved--orders of magnitude greater than fields usually available.

Status of ERA Program

Experiments have shown that relatively intense electron rings can be formed and loaded with ions; but they have shown also that the intensity can be limited by a variety of beam instabilities. The injector facility in Berkeley was developed for the purpose of investigating experimentally the problems of ring dynamics and ion acceleration. The present experiment (Compressor 4) is aimed principally at beam-instability problems, and the one being prepared (Compressor 5) is designed for demonstrating ion acceleration.

Injector Facility

The new injector began operating at the 2.0-MeV level during the first part of FY 1971 as an electron source for the Compressor-4 beam instability experiments. This use was so fruitful that the extension of the injector to the designed 4-MeV operating level was delayed until the last part of the fiscal year.

This electron accelerator has several novel features, is relatively inexpensive, and has been quite successful. It consists of a series of ferrite-loaded induction cavities driven by 40-nsec pulses from Blumlein pulse-forming lines. Each cavity contributes up to 0.25 MeV energy to the beam. Five of these cavities are tightly coupled to form a 1.25-MeV electron gun. A simple, high-current, jitter-free field-emission cathode in the form of a spiral-wound tantalum ribbon has been developed. The design also allows the use of a thermionic cathode if it is needed.

Compressor-4 Experiment

The Compressor-4 experiment has allowed a detailed look at many electron-ring instability problems. There are two general classes of instabilities--"single-particle" (low-intensity) betatron resonances and collective (high-intensity) phenomena.

The single-particle resonances, although troublesome, have been understood and successfully overcome by means of time-dependent tailoring of the magnetic field shape and by minimizing the magnetic perturbations and nonlinearities that can drive the resonances.

Among collective instabilities, we were first limited by the lowest mode of the coherent

radial instability, in which the beam precesses at the frequency $(1-\nu_r)f_o$, where ν_r is the radial betatron tune and f_o the revolution frequency. The intensity threshold of this instability was successfully raised to the point where it is no longer limiting, both by increasing the effectiveness of Landau damping and by reducing the components of the electromagnetic fields that drive this instability.

A longitudinal collective (so-called "negative mass") instability is at present limiting the intensity and compactness of the compressed electron rings at a level of about 1 to 2×10^{12} (total number of electrons per ring). Rings having up to 6×10^{12} electrons have been formed and compressed, but with unsatisfactorily large dimensions due to radial growth caused by the negative-mass effect. The conditions under which this instability occurs, its evolution, and its possible suppression by means of energy spread and by choice of electromagnetic environment are being actively investigated both experimentally and theoretically.

Compressor-5 Experiment

An experiment in accelerating ions by electron rings and studying problems in ring stability and limits in accelerating rates is being prepared. The apparatus (called Compressor 5) will be similar to Compressor 3. Although the main features of the design are fixed, and the apparatus is under construction, some details will undoubtedly be altered by the results of Compressor 4.

Once ion acceleration has been accomplished, there is a wide variety in experiments to be performed with this apparatus to determine the limits of stability of ion-loaded rings under conditions of extraction and magnetic acceleration. The effects of different ion masses and charges, different numbers of ions, different methods of focussing, different rates of acceleration, and many other parameters need investigation so as to determine design information pertinent to future accelerators.

SUPERCONDUCTIVITY PROGRAM

Our superconductivity program has resulted in a number of successful magnet systems as well as in rapid advances in fundamental studies. Perhaps the most dramatic success has been a pulsed dipole magnet, such as would be used in a future superconducting synchrotron, that reached the material short-sample limit with a low cyclic loss as predicted from theory for the 7μ diameter NbTi filamentary conductor. The central dipole field in the 4-in. aperture reached 28 kG (without iron) and the Q (ratio of peak stored energy to energy loss per cycle) was exceptionally large, with a value of 600. Several previous pulsed dipoles did not reach their material short-sample limits, and we have correlated the various magnet performances with differences in insulation and cooling patterns through a dynamic stability analysis.

DC transport magnet systems are required in accelerator-beam areas and are closely related to storage and stretching rings. A quadrupole doublet of 15-cm warm bore aperture was built by LASL for their LAMPF project. We mapped the field within the aperture and obtained the multipole field aberrations and residual fields due to trapped supercurrents. Two large transport systems have been built for Bevatron-area use. They both have 20-cm warm bore apertures. The dipole has a bending field of 42 kG and is 3 ft long; the quadrupole doublet has a gradient of 6 kG/in and each quadrupole is 2 ft long.

Surprising progress has been made in the fabrication of extremely fine superconductors.

We have carried out some 50 short-sample tests of production and experimental materials. A variety of the latter are 0.003-in. diameter wire containing superconducting filaments only 4 μ in diameter; some of these have been supplied at a 0.001-in. wire diameter with 1.25 μ filaments. Some of these tests have been carried out in the range 0 to 90 kG. We have experimentally shown that the self-field effect is much smaller than has been theoretically predicted. This is important since it affects the maximum composite wire size and the cabling together of these wires into a high-current magnet cable.

A 91-kG central field solenoid wound with NbTi superconductor has been built and used to perform short-sample tests up to 90 kG. We expect this magnet will reach 95 kG central field. The use of the stable and relatively inexpensive NbTi material to such a high field has applications in large volume, high-field magnets for detectors and polarized targets.

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BEVATRON

Edward J. Lofgren in charge

OPERATION AND PROGRAMS

During the period of this report almost 5 500 hours of machine time were scheduled for high-energy physics. The research program recorded a total of 20 893 hours of experimental work. The multiplicity of experiments (integrated hours of experimentation divided by total hours of machine time devoted to research) averaged 4.3.

The Bevatron is capable of operating approximately 320 days per year; holidays, maintenance periods, and shutdown for improvements and major changes average 45 days per year. Under recent reduced funding, ten to eleven weeks per year of additional shutdown have been necessary. Thus, the effective number of days of operation is reduced to about 244 days per year. A 2 1/2-month shutdown occurred between late December and early March. The length of this shutdown was budget-related; the timing was chosen to minimize the impact on the experimental program. Major improvement projects were carried out during this time.

Participation in our program by outside groups has continued to rise, their use of the machine being about 65% of the recorded experimental hours. Twenty outside laboratories and universities were involved in Bevatron experiments.

MACHINE DEVELOPMENT

Resonant Extraction of the EPB

The project to create an operational resonant-extraction system for the external proton beam culminated this year with the installation of the completed system. This method of beam extraction utilizes the 2/3 resonance of the radial betatron oscillations. Resonant beam growth is produced by a local field perturbation. Long beam spills may easily be produced. The local field perturbation also contains a coil to produce fast spills (~1/2 nsec).

Completion of this system involved installation of a new thin-septum magnet (M1), a new pole-face-winding power supply system, a system to suppress ripple in the Bevatron magnetic field, and expansion of the digital control system to automatically control the acceleration system of the Bevatron.

Septum Split of the EPB

The success of the system of septum-magnets installed last year in channel I of the EPB encouraged us to install a similar system to accomplish a simultaneous sharing of the extracted beam between EPB Channels I and II. This new system was installed during the shutdown in January and February of this year. Thus it is now possible to share the beam simultaneously between three end-station target areas with great flexibility. Multiple energy operation is retained as an important feature of this system.

Computer Control

The new magnet elements of the multi-channel EPB system are digitally controlled using a PDP-8 processor such that their currents are continuously related to the changing

field of the Bevatron magnet. As is the case with all the other magnets in the system, the operator may introduce special programming into the control functions.

The accelerator guide-field, under digital control for the past year, has undergone considerable refinement in control of both absolute field value and ripple components. A high-resolution field detector has achieved pulse-to-pulse stabilities of ±1 G. Digital processor control within several closed loops compensates for a wide variety of uncontrolled variations.

A comprehensive 256 channel analog/digital data acquistion system has been created for detection and ultimate reduction of incipient fault conditions associated with the ignitron rectifiers. Digital techniques have made a significant contribution to the overall improvement of guide-field quality and stability, so necessary for implementation of resonant extraction technique.

A major step was taken to achieve better and noise-free control of the rf acceleration system of the Bevatron. The low-level rf frequency modulation system with its multitude of analog correction-signal inputs was replaced with a digital system incorporating a digital processor.

High Brilliance Ion Source

The loss at injection which characterizes all large synchrotrons is not understood to date. There may be numerous contributing factors. However, a controlled emittance--and, hence, brilliance--are essential for a more efficient injection and trapping-process. Therefore we have rebuilt our 500-kV Cockcroft-Walton to give 750 kV. This system will soon be under test.

Cryogenic Pumping

Gas scattering still causes a substantial loss of particles at injection. We believe that the relatively large amount of organic compounds which are pumped poorly by conventional diffusion pump are the main problem. Hence, we are planning a cryogenic pumping system for the Bevatron vacuum tank. This system consists of a liquid-nitrogen enclosure which houses a helium line of 20° K. The combination of liquid nitrogen and low-temperature helium gas will more than double the present pumping capacity. Furthermore, the liquid nitrogen will be a great help to pump down quickly after a shutdown; in particular, water and other solvents should be removed very rapidly.

Superconducting Beam Transport

Superconducting beam transport elements were completed for test and evaluation in a Bevatron secondary-particle beam. A dipole and a quadrupole doublet were designed and built for use in high-momentum pion beams. Both are 8-in. diameter warm bore.

High-Voltage Separator

The interest in precision experiments of rare decay modes of K-mesons has increased; thus it became evident that the development of K-beams must be pursued. Since a substantial loss of low momentum K is due to decay in flight, the length of the hardware components must be reduced; this means, among other items, shorter separators with the same $\int V ds$ across the beam. An alternative solution would be to superimpose the electric and the magnetic field for separation and dispersion, respectively. Both solutions are under investigation, and some tests are under way.

High-Intensity Stopping K-Beam

The design of a high-intensity stopping K-beam is in progress. The goal is to build a separated beam which will yield 10^5 stopped

K^+ per pulse in a background of 10^6 particles; the method will be to use specially designed beam elements in a short beam with a large-solid-angle acceptance. Beams of this description exhibit very large second-order aberrations, both spherical and chromatic, which can be partially corrected with sextupole components. A program of optimizing possible beam designs and of comparing these optimized designs is under way, with the purpose of finding the best and least expensive design.

184-INCH SYNCHROCYCLOTRON

James T. Vale in charge

This accelerator, used for nuclear physics, nuclear chemistry, and medical work, is basic to the Medium Energy Physics Program of the Laboratory. Unique in its flexibility with regard to particles accelerated, it provides intense internal and external beams of protons (740 MeV) and correspondingly energetic deuterons and helium ions. Mesons and neutron beams produced by these particles are also available and are intensively used. At present, the cyclotron operates on a schedule of 19.5 shifts per week, including 0.5 shift for maintenance. About 50% of its running time is for outside groups.

Completed this year was the experiment to test time-reversal invariance by means of the reaction $np \rightarrow d\gamma$; several institutions were involved in this work: LBL, UCLA, University of Michigan, and University of Washington. The checking of time reversal by detailed balancing using $p + d \rightleftarrows {}^3He + \nu$ is currently being measured by an LBL - UC Santa Cruz collaboration.

Also finished was the measurement of the muon magnetic moment. With the same equipment, a study of the depolarization of muons in condensed media was carried out.

Use of π^- radiative capture reactions on various nuclei to study nuclear structure is continuing. Preliminary work on the π-capture γ-ray spectra has been done for ${}^4He$, ${}^{12}C$, ${}^{16}O$, ${}^{24}Mg$, and ${}^{40}Ca$.

Under way are experiments to determine the Δ magnetic moment (UCLA), to measure the spin correlation parameter for proton-neutron elastic scattering (University of Toronto), to measure the differential cross sections for $\pi^+ d$ elastic scattering (UBC), and to test for a parity difference between the muon and the electron (University of Arizona).

Calibrations for various detectors used in space physics have been carried out by NASA- and NSF-supported groups. A collaboration between Clarkson College and LASL, measuring neutron energy distributions from protons on uranium, has been completed.

The biomedical program, although it uses only approximately 7% of the accelerator time, is an important aspect of the medium-energy physics activity. This program consists not only of research with animals, but also of treatment of patients by techniques that have been well established through many years of development. The mainstay of these treatments has been the irradiation of the pituitary gland, but an expansion of the program is planned with the completion of the new body positioner, scheduled for the beginning of FY 1972.

The increasing use of the 184-inch facility by outside groups has placed a heavy load on the operation effort of the machine. To provide efficient use of the facility, the external proton beam has been developed. For one thing, a variable-energy low-flux beam was constructed. It is now possible for two experiments to share the beam simultaneously; as a result, a highly polarized muon beam, a variable-energy pion beam, and two low-energy pion beams will be set up for the current experiments, as well as for future runs.

Other improvements are:

dc power-supply annex completed; meson cave special-platform blocks completed and installed; clean-air system completed; all gaskets in the external beam tube replaced; new second-dee system begun; two new "C" magnets received and put into service; additional shielded magnet stands fabricated and put into use; an additional portable counting room constructed and put into service; the 1250-KW generator and the 2-MW generator overhauled; additional general-purpose shielding blocks procured; design and material procurement of large 22" X 66" picture-frame magnet well under way; radiation monitoring system completed; and a record number of experiments set up.

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