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PHYSICS DIVISION QUARTERLY REPORT  
August, September, October 1957

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UNIVERSITY OF CALIFORNIA

Radiation Laboratory  
Berkeley, California

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GENERAL PHYSICS RESEARCH

PHYSICS RESEARCH

Luis W. Alvarez in charge

LIQUID HYDROGEN BUBBLE CHAMBERS

Operation and Development

James Donald Gow

4-Inch Chamber

The 4-inch chamber operated essentially continuously from the beginning of August to October 15 on the neutron-spectra experiment being run for Dr. Moyer's research group. The chamber will next be used in a series of experiments at the 300-Mev electron synchrotron.

10-Inch Chamber

The 1.1-Bev  $\pi^-$ -interaction experiment described in our preceding quarterly report has continued throughout the present quarter on a 5-day, two-shift basis. This run is scheduled to terminate on December 1. During this run there was one incident worthy of note. Owing to malfunction of a magnet regulator, a violent oscillation of the magnetic field in the bubble chamber magnet occurred. The mechanical forces acting on the copper chamber were sufficiently large to break one heat leak completely loose from the chamber and to bend the expansion line. Fortunately, all welded and soldered joints in the high-pressure hydrogen system remained intact and operation continued normally. An automatic generator field-programming system, which prevents rapid changes in the generator output current, has now been installed. The field programmer is as fail-safe as possible, and should prevent similar incidents in the future.

With the exception of a short shutdown to repair the damage noted above, the chamber has operated continuously throughout this quarter.

### 15-Inch Chamber

The 15-inch chamber was mechanically completed, except for certain components of the retrodirective illumination system, by late October. A run was made using nitrogen as the working fluid. All components appeared to function in a satisfactory manner and radiation-sensitive boiling was observed in the nitrogen. The chamber was disassembled for installation of the optical components at the end of the nitrogen test. The first hydrogen operation is scheduled for November 15.

### 72-Inch Chamber

The building adjacent to the Bevatron, which will house the 72-inch chamber, compressor station, and control room, was about half completed on October 31.

The magnet has been tested to 1 megawatt power level and the magnetic field appeared to be some 10% greater than the field expected. Spot measurements indicated that the field shape at full current would be satisfactory. The magnet structure, with the exception of the means of locomotion, is considered complete.

Final machining of the chamber casting has been completed. The shop is fabricating the hydrogen-temperature thermal shield and a few miscellaneous parts. Assembly of the instrument is proceeding rapidly and a nitrogen test run is scheduled for February 1958. Hydrogen operation will be possible shortly after the completion of the building in March.

The use of an open-burner emergency vent system has been abandoned in favor of venting into an evacuated sphere. In hydrogen operation such a vent system is desirable from a public relations point of view. For deuterium operation, the sphere is essential to prevent the waste of deuterium in the event of mechanical malfunction. The sphere has been designed, and cost estimates indicate that such a venting system is economically practical.

### Optics and Data Reduction

Hugh Bradner

### 10-Inch Chamber

The 1.1-Bev/c  $\pi^-$  run has been terminated. Most of the data are analyzed. A similar run has begun, to study the production of  $\Lambda^0$  and  $K^0$  particles by 1.24-Bev/c  $\pi^-$  mesons. Events from this run are being measured.

All together, 12 IBM programs are now in existence for hydrogen bubble chamber data analysis.

### 15-Inch Chamber

An improved retrodirective reflector has been tested, and will be used in the 15-inch chamber. This reflector, based on a design suggested

by Alvarez, employs plastic bars shaped like wooden coat-hangers with polished surfaces of appropriate radii on top and bottom.

Cameras for the 15-inch chamber are to be modifications of the Recordak units employed on the 10-inch chamber. One camera has been tested; a second is being completed.

The measuring projector has been modified, and furnished with a rigid metal frame so that it will accommodate film from either the 10-inch or 15-inch chamber. A number of changes have been incorporated, to improve electronic and mechanical stability, and to increase operator convenience.

### 72-Inch Chamber

Some construction has begun on the precision data reader. The optical layout is essentially complete. Fabrication of the microscope stage is under way. The Ferranti grating system, to define stage position, has been ordered.

Camera design is under way.

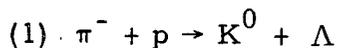
The compensating lenses mentioned in the preceding quarterly report have been abandoned.

A design for a very-high-speed reading machine is taking shape.

### Physics Research With Liquid Hydrogen Bubble Chambers

#### Results of Experiments Performed With Hydrogen Chambers

From the exposure of 1.1-Bev/c pions to the 10-inch liquid hydrogen bubble chamber the following information has been obtained from an analysis based upon approximately 70% of the data:



#### (a) Total cross section:

$$\sigma_T = 0.49 \pm .11 \text{ mb (based on 76 double V's)}$$

#### (b) Angular Distribution:

$$\frac{dN}{d\Omega} = (31 \pm 6) - (43 \pm 8) \cos \theta_{\Sigma} + (20 \pm 16) \cos^2 \theta_{\Sigma}$$

#### (c) Parity:

not conserved in the decay of the  $\Lambda$  . \*

$W(\theta, \xi)d\Omega d\xi$ , the angular distribution of the decay pion with respect

\* See Crawford, Cresti, Good, Gottstein, Lyman, Solmitz, Stevenson, and Ticho, Detection of Parity Nonconservation in  $\Lambda$  Decay, UCRL-8008, Oct. 1957.

to the polarization direction,  $\vec{P}_{\pi} \times \vec{P}_{\Lambda}$ , is given as a function of  $\theta_{\Lambda}$  (c.m.) and  $\xi$ . Here  $\xi$  is the cosine of the angle of decay with respect to the polarization direction in the rest system of the  $\Lambda$ :

$$W(\theta_{\Lambda}, \xi) d\Omega d\xi = \frac{1}{2} I(\theta) d\Omega \left[ 1 + a P(\theta_{\Lambda}) \xi \right] d\xi.$$

For S- and P-wave production,  $I(\theta)$ , the production angular distribution, is given by

$$I(\theta_{\Lambda}) = \left| a + b \cos \theta_{\Lambda} \right|^2 + \left| C \right|^2 \sin^2 \theta_{\Lambda}$$

and  $P(\theta_{\Lambda})$ , the polarization, is given by

$$P(\theta_{\Lambda}) = \frac{2 l m C^* (a + b \cos \theta_{\Lambda}) \sin \theta_{\Lambda}}{I(\theta)}$$

Since the production angular distribution is roughly  $(1 - \cos \theta)$ , then  $P(\theta)$  is just  $\sin \theta \sin \gamma$ , where  $\gamma$  is the phase angle between  $C$  and  $a (= -b)$ . The 73 double V's have been used in making a maximum-likelihood determination of the quantity  $a \sin \gamma$ . The result is  $a \sin \gamma = 0.55 \pm .23$ , which shows not only that parity is not conserved but that it is very much not conserved. Furthermore, from our total sample of data, which include single V's and double V's, we obtain, for  $a$  times the average polarization,

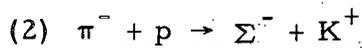
$$a \overline{P} = \frac{(N \text{ up} - N \text{ down})}{1/2 (N \text{ up} + N \text{ down})} = 0.44 \pm .11.$$

The value of  $|a|$  must be larger than these numbers, as we have  $\sin \gamma$  and  $\overline{P} < 1$ .

(d) Charge conjugation,  $C$ :

not conserved in the decay of the  $\Lambda$ . Gotto has shown that in order for  $C$  to be conserved,  $|a|$  must be less than  $0.18 \pm .02$ .

This is clearly not satisfied by the observed values of  $a \sin \gamma$  or  $a \overline{P}$ .



(a) Total cross section:  $\sigma_T = 0.22 \pm .03$  mb.

\* R. Gotto, Test of Charge-Conjugation Invariance in Hyperon Decay, UCRL-8009, Oct. 1957.

(b) Angular distribution:

$$\frac{dN}{d\Omega} = (43 \pm 8) + 17 \pm 11) \cos \theta_{\Sigma} + (52 \pm 22) \cos^2 \theta_{\Sigma} .$$

(c) Parity nonconservation:

no evidence for parity nonconservation in our  $\Sigma^-$  decays:

$$a P(90^\circ) = 0.14 \pm .20 .$$

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

(a) Total cross section:

$$\sigma_T = 0.19 \pm .04 .$$

(b) Angular distribution:

The distribution has not yet been subjected to a least-squares analysis. However, the distribution appears more isotropic than according to the data of Glaser et al. at the higher momentum of 1.2 Bev/c.

(4) Strange-Particle Interactions in Flight

(a) Hyperons

Thus far, there have been two  $\Lambda^0 + p \rightarrow \Sigma^+ + n$  events that yield a cross section of 67 mb, and one  $\Lambda^0 + p \rightarrow \Lambda^0 + p$ , which gives 33 mb.

(b)  $K^0$  particles

Two cases of  $\bar{K}^0 + p \rightarrow \Sigma^+ + \pi^0$  have been seen in which the  $\bar{K}^0$  ( $S = -1$ ) was originally produced as a  $K^0$  ( $S = +1$ ) and altered its character as a result of decay of the  $K_1^0$  part of the amplitude, thus leaving only the  $K_2^0$  component. The  $K_2^0$  is in turn expressed as a linear combination of  $K_1^0$  and  $K_0^0$ . In each case the particle interacted in the  $\bar{K}^0$  channel. From these two events one obtains a  $\bar{K}^0$  cross section close to geometrical size.

PHYSICS RESEARCH

Walter H. Barkas in charge

PADUA-VENICE CONFERENCE

During the quarter, W. H. Barkas attended the International Conference on Mesons and Recently Discovered Particles, at Padua and Venice, Italy, September 22-28, at which new results of work at UCRL were presented as follows.

Hyperon and K<sup>-</sup> - Mesons Masses and Mean Lives

A paper by Barkas, Giles, Heckman, Inman, Mason, and Smith was presented,<sup>1</sup> of which the abstract is reproduced here.

Our program of study on the interaction of K<sup>-</sup> mesons in nuclear track emulsion has led to estimates of the masses of K<sup>±</sup>, Σ<sup>±</sup>, and Λ<sup>0</sup> particles. To obtain reliable measurements, particular attention was placed in the determination of the emulsion density and shrinkage factor. The range-measurement techniques employed are the same as those developed in an extensive study of the range-energy relation for emulsion.<sup>2</sup> Area scanning for Λ<sup>0</sup> decays in the region of the stopped K<sup>-</sup> mesons has been initiated, and to date, 27 Λ<sup>0</sup> p + π<sup>-</sup> decays have been tentatively identified. The Λ<sup>0</sup> mass and its Q value are preliminary results based upon the first six events analyzed. The proton and pion masses assumed are 938.23 and 139.63 ± 0.06 Mev, respectively. The mass measurement results are as follows:

K <sup>-</sup> :	493.2 ± 0.6 Mev
Σ <sup>+</sup> :	1189.3 ± 0.3 Mev
Σ <sup>-</sup> :	1195.8 ± 0.7 Mev
Λ <sup>0</sup> :	1115.8 ± 0.3 Mev
Q <sub>Λ<sup>0</sup></sub> :	38.0 ± 0.3 Mev

This work was performed under the auspices of the Atomic Energy Commission.

<sup>1</sup>Walter H. Barkas, Peter C. Giles, Harry H. Heckman, Fred W. Inman, Conrad J. Mason, and Frances M. Smith, Hyperon and Negative K-Meson Masses, UCRL-3892, Aug. 1957; also to be published in the Proceedings of the International Conference on Mesons and Recently Discovered Particles, Padua and Venice, Italy, September 1957.

<sup>2</sup>W. H. Barkas et al., "The Range-Energy Relation in Emulsion, Parts I and II", UCRL-3768, UCRL-3769, April 1957.

In addition, our measurements of the  $\Sigma^+$  mean life as  $0.87^{+.13}_{-.10} \times 10^{-10}$  sec and the  $\Sigma^-$  mean life as  $1.70^{+.66}_{-.49} \times 10^{-10}$  sec were presented in summary reports at the conference.

Analysis of  $\Sigma$ -Hyperon Decay for Asymmetry

A paper of this title, by Harry H. Heckman, Fred W. Inman, and Frances M. Smith, University of California Radiation Laboratory, and W. Alles, N.N. Biswas, M. Ceccarelli, and J. Crussard, Max-Planck-Institut für Physik, Göttingen, was presented, as follows:

When a negative  $K^-$  meson is captured in a nucleus and only a charged pion and a charged hyperon are seen to be emitted from the star, there is a high probability that the reaction is  $K^- + p \rightarrow \Sigma^\pm + \pi^\mp$ . In general, the  $\Sigma$  and  $\pi$  will not be collinear because of the influence of the nuclear Coulomb field and the proton velocity. The  $\Sigma$  and  $\pi$  momenta then define a plane, which--aside from the smearing effect of the nuclear Coulomb field--is the production plane of the process  $p + K^- \rightarrow \Sigma^\pm + \pi^\mp$ , the proton being considered in motion and the  $K^-$  (if captured from an S state) being considered at rest.

When the hyperon decays, we are interested in the sign of the quantity  $\bar{p}_\pi \cdot (\bar{p}_\Sigma \times \bar{p}_\pi)$  in the center-of-mass system of the hyperon. In this expression  $\bar{p}_\pi$  is the momentum of the hyperon, and  $\bar{p}_\pi$  is the momentum of the pion produced in association with the hyperon.

We have gathered all available information, including our own data and those from other laboratories in the U.S.A. and Europe.

If we have

$$\frac{\bar{p}_\pi \cdot (\bar{p}_\Sigma \times \bar{p}_\pi)}{|\bar{p}_\pi| |\bar{p}_\Sigma \times \bar{p}_\pi|} \equiv \cos \theta,$$

and if we assume the distribution has the form  $1 + a \cos \theta$ , our analysis yields values of  $a$  for three cases as follows:

Decay Mode	a
$\Sigma^- \rightarrow p + \pi^0$ in flight and at rest	$-0.34 \pm .17$
$\Sigma^+ \rightarrow \pi^+ + n$ at rest	$-0.33 \pm .20$
$\Sigma^+ \rightarrow \pi^\pm + n$ in flight	$0 \pm .23$

It should be remarked that there are numerous ways in which the sign of the effect can be accidentally reversed. Because the data were gathered from a number of sources, it is possible, but not probable, that an error of this sort remains in some of the data. Any data of this sort would tend to nullify the effect, so that the absolute values of  $a$  that are quoted may be underestimated.

## PARTICIPATION IN PROPANE BUBBLE CHAMBER EXPERIMENT

Walter Duziak, John N. Dyer, Harry Heckman, and J. Patrick

A large part of this period was spent participating in a Bevatron experiment with the 30-inch bubble chamber in collaboration with Professor Wilson Powell's group. Our phase of the experiment consisted of stopping a separated  $K^+$  beam in the bubble chamber and observing the decay products. Many pictures were successfully taken and now require analysis.

Our contribution to the analysis will be primarily the study of the minor decay modes of the  $K^+$  meson. The modes of particular interest are the  $K_{\mu 3} \rightarrow \mu + \pi + \nu$  and  $K_{e 3} \rightarrow e + \pi^0 + \nu$ . Effort will be placed in the evaluation of energy spectra of the  $\mu$ 's and  $e$ 's as well as their rates of decay. A search for the  $K_{e 2}$ , unobserved as yet, will be attempted. Preliminary scanning of the film is now under way. Scanning has been concentrated on parts of the run where sufficient absorber was placed in the beam to bring the  $K$  mesons to rest in the chamber. About 600 stopping  $K^+$  mesons have been identified, of which about 4.6% were  $\tau$  particles. We have observed up to one  $K$  per three pictures. Momentum analysis of the decay secondaries has not been initiated.

 $\mu$ -MESON DECAY SPECTRUM

Walter Duziak

Much of this period was devoted to completing the reduction of the experimental data of the  $\mu$ -meson decay experiment and writing it up in report form. The writing of this report is approximately eighty percent complete.

## STUDY OF TRACKS OF NITROGEN-14 AND OXYGEN-16 IN EMULSION

Harry Heckman, P. Starring, and William G. Simon

We have exposed 50 microns of G.5 nuclear track emulsion to the  $N^{14}$  and  $O^{16}$  beams from the Hilac. Under current study are the "mean track widths" as a function of residual range of these ions, measured by photometric techniques. The work initiates an experiment that is essentially a calibration of our measurement technique and will enable use to evaluate the ionic charge of stopping nuclei in G.5 emulsion. Preliminary data indicate that over a track length of about  $125\mu$ , the ratio of the mean track widths,  $O^{16}/N^{14}$ , is  $1.14 \pm 0.04$ .

PHYSICS RESEARCH

Robert W. Birge in charge

CHARGE EXCHANGE OF POSITIVE K MESONS

Robert W. Birge, Robert E. Lanou, and Marian N. Whitehead

Cloud Chamber Study of  $K^+$ -Meson Charge Exchange

The cloud chamber film has been scanned and the following abstract will be presented to the New York meeting of the American Physical Society, January 29-February 1, 1958.

Search for Charge Exchange of K Mesons

A triggered multiplate expansion cloud chamber has been used to the Bevatron to study the charge exchange of  $K^+$  mesons.<sup>1</sup> Events that triggered the chamber were selected from a momentum-analyzed K-meson beam by a counter telescope containing scintillators and Cherenkov counters. The charge-exchange target was placed inside the cloud chamber with an anticoincidence counter behind it.

An estimate based on emulsion data, including corrections for geometry, and the assumption that one-half the charge-exchanged K mesons decay by the  $\theta_1^0$  mode suggests that five  $\theta_1$  mesons should have been seen, whereas none has been found.

The conclusion is drawn that the charge-exchange cross section is lower than expected.

Bubble Chamber Study of  $K^+$ -Meson Charge Exchange

A similar experiment has been done in collaboration with Wilson M. Powell and William B. Fowler, using their new 30-inch propane chamber. The following abstract will also be presented at the New York APS meeting.

Charge Exchange of  $K^+$  Mesons

The charge-exchange scattering of  $K^+$  mesons is being studied in the 30-inch propane bubble chamber<sup>2</sup> with particular emphasis on the behavior of the neutral  $\theta$ 's produced in the process.

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<sup>1</sup>Birge, Courant, Lanou, and Whitehead, in Proceedings of the International Conference on Mesons and Recently Discovered Particles, September 22-28, 1957 Padua and Venice, Italy.

<sup>2</sup>Powell, Fowler, and Oswald, Thirty-Inch Propane Bubble Chamber, UCRL-8037 Abstract.

A separated K beam<sup>3</sup> at the Bevatron with a momentum of 500 Mev/c and with a  $\pi^+/K^+$  ratio of about 20/1 was used as a source. A small fraction of the 50,000 pictures that were taken has been roughly scanned to date and one  $\theta_1^0$  decay resulting from a charge exchange in the liquid has been found.

The rough preliminary scan shows fewer  $\theta_1^0$ -type decays than predicted on the basis of the emulsion data, assuming that 50% of charge-exchange events result in  $\theta_1^0$  decays.

### SCATTERING OF K MESONS ON PROTONS

Leroy T. Kerth and Thaddens Kycia

The set of 15 annular ring counters, which define the scattering angle, has been designed and built. The counters are being mounted inside an iron frame which acts both as a support and as a magnetic shield.

The liquid hydrogen target is presently in the assembly stage. The Mylar container for the liquid hydrogen has been built and tested. A similar Mylar container was found to withstand, at 77°K, an internal pressure of 93 psi against a vacuum before bursting.

### $\pi$ - $\mu$ DECAY

Nuclear emulsion plates exposed at the Chicago cyclotron have been scanned for  $\pi^+$  mesons. Twenty-five hundred decays at rest have been measured to determine if any asymmetry exists as reported by C. Lattes. Of these, 1500 were found by area scanning and 1000 by track following. The final analysis has not been completed but there appears to be no effect as large as that originally found by other workers.

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<sup>3</sup>Designed by Donald H. Stork and John Mulvey

THEORETICAL GROUP

David L. Judd in charge

ATOMIC AND MOLECULAR PHYSICS

A paper dealing with the results of self-consistent calculations for atoms of large atomic number was presented at the meeting of the American Physical Society in Boulder, Colorado, September 5-7. These calculations make use of single-particle wave functions which satisfy the Dirac equation for the product wave function of the atom. They therefore include relativistic effects. These results were shown to be in substantially better agreement with experimental results than previous nonrelativistic calculations. Results for the ground states of the normal atoms Pt, W, Hg, and U were presented. A further calculation on similar solutions for the normal Pu atom is at present in progress. (Stanley Cohen)

The calculations on the  $\mu$ -mesic molecules and the processes related to their formation are continuing. In particular the formation of  $(pp\mu^-)^+$  molecular ions is being investigated at the present time. A cross section for the transfer of a  $\mu$  meson from a proton to a deuteron has been obtained and the consequences of this are being determined. (Stanley Cohen, David L. Judd, and Robert J. Riddell, Jr.)

A study of the spin-dependent Compton effect and polarization of bremsstrahlung photons is being undertaken, with the intent to investigate polarization of electrons in  $\mu$  decay. (Robert Profet)

Work is continuing on the polarization effects in bremsstrahlung and pair production for relativistic energies. Some attention is being directed to the energy range of 10 to 40 Mev with regard to  $\mu$ -decay experiments. Calculations were made preparatory to programming the problem for the IBM 650; a flow chart has been made and work begun on the actual coding. Some time was spent in applying a numerical-analysis procedure to the equations in advance of coding. (L. F. Cook, Jr., and Neville A. Williams, Jr.)

An attempt is being made to extend some earlier work on the theory of magnetic poles. (Joseph V. Lepore)

## SCATTERING, NUCLEAR FORCES, AND NUCLEAR MODELS

A systematic study of the scattering of  $K^+$  mesons by nucleons is being undertaken to see if a simple field theoretical description of the experimental observations is possible. In particular an effort is being made to deduce the value of the K-meson coupling constant. (Geoffrey F. Chew and Zaven Guiragossian)

A study has been made of the theory of inelastic scattering of high-energy protons from light nuclei and its possible effect on the elastic differential cross section. Attention was restricted to the case in which only one level is strongly excited. The interaction is assumed to be a direct interaction between the incident nucleon and a single nucleon in the nucleus. This can be studied by perturbation theory or by a strong-coupling model: this model treats the nucleus as a medium with two coupled levels, and the wave propagates in such a medium with two normal modes, giving quite simple optical properties. Such a model gives general features similar to those of other direct-interaction theories, but the details depend on the form of the interaction. Unless the coupling is very strong such a model is no easier to work with at high energies than perturbation theory; qualitative differences can be studied easily by using a square-well potential. (D. J. Thouless)

Optical-model analysis of low-energy neutron scattering by nuclei<sup>1</sup> suggests that the imaginary part of the optical-model potential is strongly peaked at the nuclear edge. The imaginary potential was calculated for a degenerate Fermi gas contained in a large box with sloping sides. The slope of the sides was chosen so that the density of nucleons at the edge varied approximately as for real nuclei. For such a case there is no peaking of the imaginary potential, but there is an extension of the imaginary potential beyond the real well at the point of half density of about  $0.6 \times 10^{-13}$  cm. If it is assumed that the real well is energy-dependent so that the nucleons possess an effective mass, then one finds indeed a substantial peaking of the imaginary potential at the nuclear edge. However, in this case, the magnitude of the imaginary potential is much too small. (Warren Heckrotte)

The lowest-order three-body potential between a  $\Lambda$  particle and two nucleons has been calculated. The purpose of this investigation is to compare such a three-body potential with the usual two-body potentials and to estimate its effect in the binding of hyperfragments. (Richard Spitzer)

An attempt is being made to investigate the effect of nucleon recoil in the Yukawa interaction. The single pion-exchange interaction is to be calculated without making the usual approximation that the nucleon is infinitely heavy. A nonlocal interaction will result which will require the solution of the Schrödinger equation for the two nucleons in integral rather than differential form. (How-sen Wong)

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<sup>1</sup>Bjorklund, Fernbach, and Sherman, Phys. Rev. 101, 1832 (1956).

A theory of the effects of a possible resonant state of the  $Y-\pi$  system is being carried out. (R. Gotto)

Work on two problems encountered by the experimentalists of the Alvarez group in their associated-production experiment has been completed.

(a) Relations between the polarization of  $\Sigma^0$  and  $\Lambda^0$  in  $\Sigma^0$  decay. It has been found that the  $\Lambda^0$  polarization is longitudinal in the  $\Sigma^0$  rest system, and it averages to  $\frac{1}{2}$  of the  $\Sigma^0$  polarization. The first result is physically important because it could lead to observation of a forward-backward asymmetry (without parity doublets). The second result has been useful in determining experimentally the lower limit for the asymmetry parameter in  $\Lambda^0$  decay.

(b) Conditions imposed by charge independence on the polarizations in associated production. It has been found that two sets of triangular inequalities must be satisfied by the polarizations and the cross sections. (R. Gatto)

Corrections to the Born-approximation terms for the pickup process have been partially calculated. These corrections lower the magnitude and spread out the angular distribution for the differential cross section. In addition, calculations based on an optical-model formalism are being started. (Kenneth Greider)

The high-energy end of the neutron energy spectrum produced in the reaction  $p(d, 2p)n$  for incident protons of about 10 Mev has been calculated and is found to be in reasonable agreement with experiment. Previous calculations of this process to be found in the literature have ignored the effect of the final-state interaction of the two protons and thus do not reproduce the structure of the high-energy end of the neutron spectrum. (Warren Heckrotte)

A calculation of the photoproduction of  $\pi^+$  mesons from deuterons is being carried out in the impulse approximation, using the dispersion-relation formula of Chew, Low, etc. for the one-nucleon amplitudes. The final state of the deuteron system is approximated by plane waves. Preliminary numerical calculations are not in good agreement with experiment, and a search for possible errors in the computations is in progress. (Jack L. Uretsky)

The study of the deformation energy of a uniformly charged drop was continued in connection with the liquid-drop theory of nuclear fission. The surface and electrostatic energies of the drop were calculated by means of an expansion about the spherical shape taken to sixth order in the distortion which is described by an arbitrary superposition of the Legendre polynomials of orders 1 through 7. This expansion provides simple and rather accurate expressions for the so-called "saddle-point shapes" and the associated fission thresholds. The expansion was also applied to a study of the stability of the saddle-point shapes against small asymmetric distortions. Further study of the nature of the deformation energy by means of the sixth-order expansion suggested some hitherto unsuspected features, namely the possible existence of several distinct families of saddle points, associated with distinct modes of fission. These possibilities call for a revision of the conventional theory of fission; in particular the discussion of the dependence of fission threshold on

the nuclear parameter  $Z^2/A$  would be modified and the occurrence of qualitatively different modes of fission for different values of  $Z^2/A$  would seem to be understandable. In order to make a quantitative study of these possibilities, more comprehensive electronic machine calculations of the deformation energy of a drop are being made in collaboration with Dr. David Hill at Los Alamos and Frank Bjorklund at Livermore. In addition, further work using improved techniques based on expansions about an ellipsoid has already confirmed the existence of saddle-point shapes other than those studied in the conventional theory of fission. (W. J. Swiatecki)

The statistical theory outlined in the preceding report has been put in a form suitable for practical calculations of physically interesting multiple processes. These are now being carried out. An outline of this work is being prepared for publication. (Maurice Neuman)

### ANTINUCLEONS

The calculation of the nucleon-antinucleon interaction by the model outlined in the preceding Physics Quarterly Report has yielded encouraging results. It appears that the large antinucleon cross sections can be understood within the frame work of the Yukawa theory as due to the exchange of virtual pions. The nucleon-nucleon cross sections produced by the same mechanism are smaller as a result of systematic cancellations which do not occur in the nucleon-antinucleon system. Predictions as to the behavior of the annihilation and elastic scattering of antinucleons in the energy range from 50 to 200 Mev, so far unexplored experimentally, have been made on the basis of the model. This work is described in a separate report.<sup>2</sup> (James S. Ball and Geoffrey F. Chew)

A program is now being undertaken in collaboration with Kenneth Watson (Physics Department) and Sidney Fernbach (Livermore) to calculate the interaction of antinucleons with complex nuclei on the basis of the above ideas. Definite predictions on elastic-scattering angular distributions and polarization as well as total cross sections will be possible. (James S. Ball and Geoffrey F. Chew)

A new project in studying the proton-antiproton annihilation is under way. An attempt is being made to relate the annihilation amplitude for producing  $n$   $\pi$  mesons to the amplitude for producing  $(n-1)$  mesons. (Jack L. Uretsky with Charles Zemach)

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<sup>2</sup>Geoffrey F. Chew and H. Pierre Noyes, Dispersion Relations for Scattering in the Presence of a Coulomb Field, UCRL-3869, July 1957.

## DECAY OF STRANGE PARTICLES

From the earlier general theory of the correlations in the production and decay of spin- $3/2$  hyperons, the form of the azimuthally averaged decay angular distribution when only S and P waves are effective in the production has been reduced to an expression involving only the measured parameters of the production experiment and a single additional constant. Severe limits on this constant are obtained. The formula is an extension to nonzero production angles of the formula of Adair, and will be useful in determining the value of the hyperon spin. (Henry P. Stapp)

An attempt is being made to describe the decays of the hyperons and K mesons by one universal interaction. (Owen Eldridge)

The upper limit on the asymmetry parameter in  $\Lambda^0$  decay imposed by charge-conjugation invariance has been calculated as  $0.18 \pm 0.02$ . From the value found by the Alvarez group,  $|a| > 0.44 \pm 0.11$ , it can be concluded that charge-conjugation invariance is violated in  $\Lambda^0 \rightarrow p + \pi^-$ .<sup>3</sup> (R. Gatto)

A phenomenological analysis of  $\mu$  decay done in collaboration with A. Klein has been submitted to the Physical Review for publication. In addition to the nonlocal interactions considered recently by Lee and Yang, there may be terms appearing phenomenologically as derivative couplings. In particular, a spectrum that is linear in momentum, aside from the statistical factor, is possible with  $\rho \neq \frac{3}{4}$ . This could be interpreted as evidence that fermions of baryonic mass  $\frac{3}{4}$  are responsible for the nonlocality. (Sidney A. Bludman)

## SYMMETRY PRINCIPLES

The TCP theorem plays a decisive role in obtaining simple structures for field theoretical Green functions. (Since, according to Jost and to Wightman and Schweber, the TCP theorem follows from invariance with respect to the proper Lorentz group and microscopic causality, and since these assumptions are always made in discussions of Green functions, no additional postulate is involved.) One finds as a consequence of the theorem that a Green function of two variables, each connected with a different Hermitian field, has the usual structure of an integral over  $\Delta_F$  functions. One also finds that Green functions of three variables depend only on the scalar product of difference vectors and not also on  $\theta$  functions of these vectors if they are timelike. (Gerhart Lüders)

The concept of Pursey-Pauli invariants (see preceding Quarterly Report) has been applied to  $\mu$ -e decay and to K decays. Since the mass of the electron can be neglected for practical purposes in  $\mu$ -e decay and in  $K_{e3}$  decay, one has a further group of transformations applicable to expressions for intensity and longitudinal polarization of the decay electrons. This observation makes the invariant fall into two different classes. Various symmetry properties have been expressed in terms of these invariants. A recent paper by Kinoshita and Sirlin has been used to express experimental information on  $\mu$  decay in terms

<sup>3</sup>R. Gatto, Test of Charge-Conjugation Invariance in Hyperon Decay, UCRL-8009, Oct. 1957.

of the invariants. A detailed discussion of the question of locality of the Fermi vertex has been given for K decay. Detection of a possible up-down asymmetry, with respect to the  $K_{\mu 3}$  decay plane, of the electrons from the subsequent  $\mu$  decay has been discussed as a possible test of time reversal.<sup>4, 5</sup> (R. Gatto and Gerhart Lüders)

Work is in progress on the general question of a universal Fermi interaction. (Sidney A. Bludman)

The relation between the theory of weak interactions recently proposed by Gell-Mann and Feynman (GM-F theory) and the theory proposed by Gatto<sup>6</sup> has been examined. The GM-F theory is obtained from the theory presented by Gatto by a particular choice of the coupling constants which is determined by the following three additional postulates: (a) only the left-handed neutrino exists; (b) also for the baryon operators, and not only for the lepton operators, weak interactions are invariant under the  $e^{i\alpha}\gamma_5$  transformation; (c) the values of the coupling constants for different processes are simply related (universal Fermi interaction). If (b) turns out to be true it will constitute the first example of an invariance property that is satisfied by weak interactions and not by strong interactions (if it is true that the nucleon-pion coupling is  $\gamma_5$  and not  $\gamma_5\gamma_\lambda$ ). (R. Gatto)

It has been shown that, if the  $\rho$  value in  $\mu$  decay is  $\sim 0.68$ , as indicated by the recent experiments, the Gell-Mann-Feynman principle of nonrenormalization of the vector coupling cannot be maintained in its simplest formulation. (R. Gatto)

#### NUMERICAL ANALYSIS

In September the IBM 650 was moved from Bldg. 50 to Bldg. 47, and operation in that building has continued without further interruption. The new model of the 650 is due for installation on November 12. This new model will include index registers, floating-point arithmetic, and alphabetic input-output. Building 47 is near completion and it is hoped that the entire mathematics group will soon be housed in their new offices in that building. (Kent Curtis)

Mathematicians in the theoretical group have been occupied as follows during the preceding quarter.

The program to analyze the reaction  $\pi^- + p \rightarrow \theta^0 + \Lambda^0$ , which was described in the preceding Quarterly Report, has been continued. A matrix

<sup>4</sup>R. Gatto and Gerhart Lüders, Invariants in Mu Decay, UCRL-3935, Sept. 1957.

<sup>5</sup>R. Gatto, Invariants in  $K_{\mu 3}$  and  $K_{e 3}$  Decays, UCRL-3949, Sept. 1957.

<sup>6</sup>R. Gatto, A Possible Theory of Weak Interactions, UCRL-3921, Aug. 1957.

subroutine to transform vectors from the chamber axes to the decay coordinate system has been written. (Seymour Singer for Lynn Stevenson)

Work has continued on the IBM 701 program to compute coefficients and eigenvalues for spheroidal wave functions. (A.D. Johnson for Jack L. Uretsky)

The existing conversion routine for converting binary-exponent floating-point numbers to decimal-exponent floating-point numbers is not sufficiently accurate. A new routine following a suggestion of Kent Curtis has been coded and is now being checked. (A.D. Johnson)

A program has been written which computes cross sections for photo-production of  $\pi^+$  mesons from the deuteron. (Marjory Simmons for Jack Uretsky)

A program for the IBM 650 to compute scattering tables for  $\pi$  mesons scattered from H, D, C<sup>12</sup>, Cu<sup>63</sup>, and Pb<sup>208</sup> has been written and is nearly ready for production. (Alice McMullen for Victor Perez-Mendez)

Work was completed on the IBM 701 program for the computation of tables used in a study of continuous-flow separation methods, which was described in the preceding report. (Alice McMullen for Theodore Vermeulen)

During the preceding quarter a three-body phase-space program called TABS was written to calculate the differential momentum spectrum for any particles of a three-body final state. The program also calculates the distribution in the Q value between any two outgoing particles i and j. The total momentum-space volume is not calculated, but the program could easily be modified to accomplish this. A more detailed description may be found in engineering note No. 4320-60 M3. (Charles Stableford for the Bubble Chamber Group)

A board has been wired for the new 650 to accommodate the IBM Symbolic Assembly routine known as SOAP II, and a board has been also wired for the 402 printer to be used for SOAP II input and output cards. A complete description of the new boards and their functions will be available shortly. (Charles Stableford for the Theoretical Group)

A program was written that computes parameters used in the construction of ellipse plots which are, in turn, used in the kinematic analysis of nuclear reactions having three bodies in the final state, one of which is neutral. This program was checked out for one nuclear reaction and is currently ready for use. (Matthew White for Bruce McCormick)

A program was written to analyze small-angle antiproton scattering in nuclear emulsions. Several potentials have been used to compute the differential scattering including Coulomb interference effects. Work on this analysis is continuing. (Donald Steinberg for Jack Sandweiss)

Work has begun on a revision of a program to compute scattering tables for any two-body scattering reaction. It is hoped that the revised program will provide flexibility, which has been lacking in the existing routine. (Donald Steinberg for Kent Curtis)

Orbits of charged particles in the magnetic field of the Bevatron were computed on the IBM 650 for several different applications. (Victor Brady for Frank Crawford, William Wenzel, Howard White, and Lloyd Smith)

Debugging of an IBM 701 program for a study of the reaction cross section for the emission of two nucleons by a heavy nucleus excited by a proton, using the impulse approximation, is continuing. (Tom Clements for Les Winsberg)

The program for the solution of simultaneous differential equations, which was reported in the preceding Quarterly Report, has been assembled and is being checked out. (Robert Harvey for Kent Curtis)

A program to compute kinematical quantities of interest in the study of  $\delta$  rays was written and run on the modified IBM 650 at Livermore. (Robert Harvey for Frank Crawford)

The program written for the study of emission of two neutrons from a nucleus excited by  $\alpha$  particles, using a statistical model of the nucleus, was completed and run on the IBM 701. (Robert Freeman for William Wade and Bernard Harvey)

A modification of the above program to treat the case of three-neutron emission is being prepared. Debugging is nearly completed. (Robert Freeman for Paul Donovan)

In connection with the study of cyclotron regenerators, it was desired to know the final distribution in phases and amplitudes of the beam particles that results from a certain number of perturbations by the regenerator (the initial distribution being known). A Monte Carlo program for the IBM 650 has been written for this purpose. In particular, the fraction of the particles lost to the cyclotron boundaries as a function of the regenerator design parameters is being computed. (Donald Itzel for Warren Stubbins)

The bubble chamber data-reduction program Hydro II has been completely edited and a detailed program listing is now available. (Richard Mitchell for the Bubble Chamber Group)

A program is being written which converts output from Hydro II into a form for use in subsequent analysis. In the course of this work an arc sine subroutine was written for the IBM 650 which gives the arc sine in degrees with an accuracy of  $0.01^\circ$ . (Richard Mitchell for the Bubble Chamber Group)

Work on the spiral-orbit spectrometer resolution and  $\mu$ -meson decay curves, which was reported in the preceding Quarterly Report, has been continuing. In particular, a program was written to combine several Michel curves with

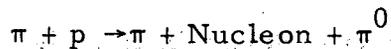
various  $\Lambda$  values. The resultant curve was then folded into a triangular-shaped background distribution. Another program was written which folds the spiral-orbit resolution curves into the energy spectrum resulting from a monoenergetic source of electrons suffering radiation and ionization losses. (Michael Lourie for Walter Dudziak)

The differential analyzer was moved from Bldg. 64 to Bldg. 47 and then refinished and readjusted. It is now ready for use in its new location. (Jonathan Young)

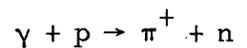
PHYSICS RESEARCH

A. C. Helmholtz in charge

Reported by Robert W. Kenney



An absolute calibration of the photon-counting efficiency as a function of photon energy was made for the  $\pi^0$ -decay gamma-counter telescope which will be used in the investigation of the above reaction at cyclotron pion energies. The counter was placed in the synchrotron beam and a photon-difference technique was employed to bind the energy dependence. The data are being reduced and no final values are available at this time. (John Caris, Robert W. Kenney, Edward Knapp, Victor Perez-Mendez, and Walton Perkins)



The angular distribution for the above reaction was measured in the angular range from  $40^\circ$  to  $165^\circ$  (c. m.) and for photon energies of 260 Mev and 290 Mev. In combination with our previous data at 260 Mev and for angles from  $0^\circ$  to  $53^\circ$ , these data give a distribution for the above reaction throughout the complete angular range, determined at a single laboratory under the same running conditions. The 290-Mev distribution will be investigated in the entire angular range in the near future.

The  $\pi^+$  counter telescope for this experiment was placed in the cyclotron  $\pi^+$  beam and an absolute counting efficiency determined for the range of pion energies encountered in this photomeson reaction. (Robert W. Kenney, Edward Knapp, and Victor Perez-Mendez)

 $\pi^-$  Scattering from Nuclei

The scattering of  $\pi^-$  mesons of 370 Mev from various nuclei has been observed in good and bad geometry as well as at intermediate points. The angular range of scattering for C was  $0^\circ$  to  $63^\circ$  and for Cu and Pb was  $6.5^\circ$  to  $63^\circ$ . Preliminary data are being reduced to yield both the absorption and diffraction-scattering cross sections for pions incident on these nuclei. The experiment is being undertaken to find the optical-model constants for several nuclei in the above interaction. (Duane Gates, Robert W. Kenney, Victor Perez-Mendez, and William Swanson)

PHYSICS RESEARCH

Edward J. Lofgren in charge

EXPERIMENTS ON ANTINUCLEONS AND K PARTICLES

Bruce Cork, William Galbraith, Glen Lambertson,  
William Wenzel, and Charles Coombes

K- $\mu$ -e Asymmetry

It has been observed that  $K_{\mu 2}$  mesons do not conserve parity during the weak interaction decay process. The observed asymmetry is of the same magnitude and direction as the  $\pi$ - $\mu$ -e chain. This experiment has been reported at UCRL<sup>1</sup> and in a Letter to the Editor of the Physical Review.

Electrostatic Beam Separator

The 20-foot-long electrostatic separator has been assembled and operated at greater than the  $\pm 160$ -kv design voltage. The magnetic field has been measured and observed to be as designed. Measurements are now being made of the separation of 900-Mev/c pions from protons.

Antinucleon Experiments

Equipment is being built and tested for the low-momentum antiproton cross-section measurements. The 12-inch-long liquid hydrogen target has been designed, and structural tests have been made of several of the critical items. Counters have been built to detect the large angle scattered particles from antiproton interactions in this target.

30-INCH PROPANE BUBBLE CHAMBER

Warren W. Chupp and Sulamith Goldhaber

We are continuing our efforts in developing facilities for projection scanning of pictures from the 30-inch propane bubble chamber. The design specifications for a standard projection scanner are virtually complete.

Our scanning effort has been primarily directed toward analyzing the emulsion stack that was exposed during the 490-Mev/c  $K^+$  run with the chamber. This stack is to provide data on the absolute flux of  $K^+$  mesons through the chamber and the ratio  $\pi^+/K^+$ . The present scanning is being carried out in more detail than necessary to provide this information. We are attempting to find and analyze more  $K^+$ -H scatterings to supplement the data we have previously

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<sup>1</sup>Coombes, Cork, Galbraith, Lambertson, and Wenzel, The Polarization of  $\mu^+$  Mesons from the Decay of  $K^+$  Mesons, UCRL-8003, Oct. 1957.

accumulated. These data are very much needed to supplement what will be obtained from the bubble chamber run and to offset the low detection efficiencies that exist at low energies and small scattering angles.

PHYSICS RESEARCH

Burton J. Moyer in charge

 $K^0$  PRODUCTION AND DECAY

John Osher and Sherwood I. Parker

In a Bevatron run during parts of July, August, and September, the final data were taken for an experiment studying the production and decay of the  $K^0$  meson. The experiment, part of which has been described in greater detail in earlier reports,<sup>1</sup> studies the decay products of the  $K^0$  mesons that decay within a few inches of the Bevatron target. Data were taken in an attempt to measure the following quantities by the means indicated.

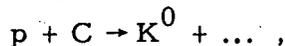
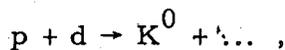
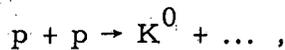
- (a)
- The branching ratio,

$$(K_1^0 \rightarrow \pi^0 + \pi^0) / (K_1^0 \rightarrow \pi^+ + \pi^-),$$

by using the apparatus described earlier to distinguish the decay  $\gamma$ 's from the  $\pi^0$ 's and by using a charged-particle telescope to detect the  $\pi^+$  and  $\pi^-$ .

- (b)
- The angular distribution of the  $K^0$  in the reaction  $p + n \rightarrow K^0 + \dots$ ,
- by moving the shielding and detectors in circles so that they measured the relative intensities of decay particles coming from various positions around the target.

- (c)
- The cross sections
- for the reactions



by studying the decay products from 3- and 6-Bev protons on  $CH_2$ ,  $CD_2$ , and C.

Monitoring of the Bevatron beam in parts (a) and (c) was by use of a charged-particle telescope aimed at the target, and also by radioactivity measurements on Al and Au foils placed on the target ( $p + Al \rightarrow Na^{24} \rightarrow \beta$ ;  $p + Au \rightarrow Tb^{149} \rightarrow \ell$ ).

<sup>1</sup>John Osher,  $\pi^0$  Modes of Heavy-Meson and Hyperon Decay (Thesis), UCRL-3449, June 1956.

ANGULAR DEPENDENCE OF NEUTRON SPECTRA  
FROM 32-Mev PROTON BOMBARDMENT OF THIN TARGETS

Harold E. Adelson, Hoyt A. Bostick, and Charles N. Waddell

The measurement of neutron-energy spectra from thin targets bombarded by 32-Mev protons at the linear accelerator using the 4-inch hydrogen bubble chamber has been completed.

Six targets (beryllium, melamine, aluminum, cobalt, nickel-58 and nickel-60) were run at three angles:  $53^\circ$ ,  $90^\circ$ , and  $127^\circ$  (laboratory system).

The data are currently being analyzed with the Benson-Lehner "Oscar."

ATTEMPT TO OBSERVE ANTINEUTRON PRODUCTION AT BEVATRON TARGET

Wilmot N. Hess, C. K. Hinrichs, Burton J. Moyer, John O. Osher, and  
Roger W. Wallace

A first effort to observe the reaction  $p + p \rightarrow \bar{n} + \text{He}^3$  was made at the Bevatron during the quarter just ended. The aim of this experiment is to provide a source of antineutrons, identified as such, with sufficient intensity and with known momentum so that attenuation experiments can be performed that will yield interaction cross sections for antineutrons in matter. The only source of antineutrons thus far identified is the charge exchange of antiprotons, and this has not thus far provided a sufficient number to allow reasonable attenuation experiments to be performed.

In the effort which was made, a  $\text{He}^3$  telescope was situated on the selected momentum orbit for positive particles emerging from a Bevatron target (which could be either C or  $\text{CH}_2$  by choice). The telescope included a liquid of low index of refraction, which was to reject  $\text{He}^4$  particles of the selected momentum whereas it would respond to  $\text{He}^3$  particles (together with the enormously greater number of protons and pions). In addition to this counter, there were also two Cherenkov counters of the Fitch type, which ought to have failed to respond to particles moving as rapidly as the protons and pions in the momentum orbit, whereas it did record the passage of particles with the  $\text{He}^3$  velocity. There were in addition three scintillator counters biased against small pulses from minimum ionization events.

At a companion angle, dictated by the kinematics of the reaction, and at a distance of 80 feet from the target was the array of lead glass Cherenkov counters in which annihilation events from antineutron interactions within the glass could be recorded. The solid angle subtended by the glass was related to that presented by the helium telescope in terms of the kinematics of the two-body reaction under investigation. The glass array, of course, was subjected to very intense exposure to ordinary neutrons. In addition it received a great many high-energy photons from the  $\pi^0$  mesons created in the Bevatron target, but these were in large measure attenuated by a uranium converter slab which was elevated with every beam pulse inside the Bevatron field between the target and the glass array.

In order to secure as great a yield as possible, in view of the estimated magnitude of the cross section for this reaction, the solid angles presented by the helium telescope and the glass array were made as large as was deemed possible in terms of their proper performance as counters. The result of this, however, was to accept a rather broad momentum group in the  $\text{He}^3$  orbit, and also a rather broad spread in angles of trajectories through the  $\text{He}^3$  telescope system. These facts prevented the proper discrimination on the part of the Fitch counters, and also on the part of the low-index counter, to such an extent that we could not obtain a clear identification of the  $\text{He}^3$  particles against the tremendous background of other charged particles traversing the telescope. However, a number of coincidences were recorded on film which display appropriate pulses in the glass array, together with eligible events in the  $\text{He}^3$  telescope elements. The film data are now being tabulated for the C and  $\text{CH}_2$  targets in order to identify the cross section for the reaction.

### NEUTRON CROSS-SECTION MEASUREMENTS AT THE BEVATRON

John H. Atkinson, Wilmot N. Hess, Victor Perez-Mendez, and Roger W. Wallace

The experiment to measure high-energy neutron cross sections is progressing. Neutrons are detected by a counter telescope in which they produce high-energy  $\pi$  mesons, and these mesons are counted. It was found that a considerable fraction of the counting rate of the gas Cherenkov counter used to count the secondary  $\pi$  mesons was due not to  $\pi$  mesons but to electrons (probably from  $\pi$  mesons produced in the converter in the counter telescope). This trouble is being eliminated by putting several radiation lengths of lead in the telescope after the converter and then a magnet to sweep out the low-energy electrons. When this is done we should have an energy threshold for neutrons of 2 Bev or maybe higher.

Two steps have been taken to increase the counting rate of the equipment. First, a new target has been installed in the Bevatron, attached to the inner radius, to catch the spill from other targets. This increases the counting rate by about a factor of 10 without expending any of the useful beam of the machine. Secondly, a larger gas Cherenkov counter has been built to count secondary  $\pi$  mesons more efficiently. This also should increase the counting rate by a factor of 10.

## CLOUD CHAMBER STUDIES

Wilson M. Powell in charge

### 30-INCH PROPANE CHAMBER

The first Bevatron run with the 30-inch propane chamber was successfully carried out during this quarter. The chamber, with associated equipment, was moved to the Bevatron during the third week of August. After the high-energy separated  $K^+$  beam had been reestablished, pictures showing  $K^+$  particles which enter with 150 Mev kinetic energy and stop in the propane were obtained. About one-tenth of the charged-particle flux was composed of K particles, therefore a rate of one to two K stoppings per picture was possible with  $\sim 10^{10}$  protons per pulse hitting the target. Photographs of nonstopping (190-Mev) $K^+$  particles were also taken. A total of 50,000 stereo pairs was taken by September 17. The first 5,000 are of low quality owing to initial operating difficulties. Approximately 70 to 80% of the remaining pictures should be suitable for analysis. The cloud chamber group, composed of Zvi Danenberg, R. Ellison, William B. Fowler, Robert Good, Ronald E. Hintz, Fred N. Holmquist, David Hotz, Richard L. Lander, Peter Newcomb, Larry Oswald, Wilson M. Powell, Wesley M. Smart, and Richard G. Thomas was assisted by Robert W. Birge, Warren W. Chupp, Kroxie Delise, Walter F. Dudziak, John N. Dyer, Harry H. Heckman, Robert E. Lanou, Joseph E. Lannutti, Jack W. Patrick, and Marian N. Whitehead. The large number of people required is illustrative of increased complexity of equipment and the 7-day-a-week operation. We believe that for future runs three people per shift will be required, or a minimum of twelve people for four shifts, seven days a week.

Since the automatic film developer did not arrive in this quarter, film development has been a primary problem. Only half the film has been developed to date.

Design and construction of scanning and measurement equipment is proceeding. Measurements with the digitized microscope with computer processing for angles and momenta should be accomplished early in the next quarter.

During the run, difficulties were experienced with cameras, compressor, and top glass position indicators. Corrective measures have been taken to assure no further trouble from these components. It is to be noted that all troubles were with associated equipment whereas the chamber itself operated well.

Additional improvements in future pictures will result from better temperature uniformity for reduction of optical distortion, more nearly monochromatic light for reduction of chromatic aberration, and a concrete shielding house for the reduction of low-energy electron background.

### 12-INCH PROPANE CHAMBER

Preparation of the 12-inch propane chamber for two runs at the cyclotron was completed during this quarter. The first exposure will be in the external proton beam and is for the purpose of looking at the Fermi momentum distribution of the nucleons in carbon nuclei. Larry Oswald and John Wilcox are primarily interested in these pictures. The second experiment will use  $\pi^+$  mesons incident

on the propane. Maximum energy  $\pi^+$ 's are required since we hope to examine meson production by the incoming pions. A primary difficulty will be obtaining a suitable beam. Richard Thomas is planning this experiment.

#### REPORT ISSUED

An abstract, "Evidence for Excited-Nucleon Model of Pion Production in n-p Collisions at Bevatron Energies," by Fred N. Holmquist, William B. Fowler, and Wilson M. Powell, UCRL-3969, Sept. 1957, was submitted for the meeting of the American Physical Society at Stanford, California, December 19-21, 1957.

PHYSICS RESEARCH

Emilio Segrè in charge

ANTIPROTON STUDIES

We have planned and prepared experiments on:

- (a) Excitation functions, angular distribution, and momentum distribution for production of antiprotons in carbon and polyethylene. Information on the hydrogen-production cross section should be obtainable by the difference. In conjunction with this experiment we plan also to determine if the antiprotons that are generated are polarized; this is in preparation for a possible measurement of the magnetic moment of the  $\bar{p}$  and for other investigations with polarized  $\bar{p}$ . We will also try to measure the elastic  $p\text{-}\bar{p}$  cross section at 1.05 Bev/c at angles from  $4^\circ$  to  $20^\circ$ .
- (b) Observation of antiprotons in the propane bubble chamber and in the hydrogen bubble chamber in collaboration with the Powell and Alvarez groups. The purified beam has been studied in detail on the basis of the experimental test of December 1956.
- (c) Large-scale irradiation of photographic plates, again using the experience on the purified beam acquired in December 1956.

These experiments await Bevatron time and also the availability of the bubble chambers and magnets.

An experiment to measure the angular distribution in the reaction



has been planned and instrumented. (Steiner, Wiegand, and Ypsilantis)

CYCLOTRON EXPERIMENTS

The preparation of experiments indicated in the preceding quarterly report continues. Runs have been performed to study the polarization tensor of deuterium.

ARC RESEARCH

Chester M. Van Atta in charge

Material for this section had not been received at the time of publication, but may be expected in a subsequent report.

ACCELERATOR OPERATION AND DEVELOPMENT

BEVATRON

Edward J. Lofgren in charge

A report for August, September, October 1957 is to be issued separately under the title "Bevatron Operation and Development. XV."

184-INCH CYCLOTRON

Robert L. Thornton in charge

Material for this section had not been received at the time of publication, but may be expected in a subsequent report.

60-INCH CYCLOTRON

W. B. Jones in charge

OPERATIONS

Summary of operations as prepared by P. McWalters for this quarter:

Alpha bombardments	854.0 hr
Deuteron bombardments	264.8 hr
Proton bombardments	100.5 hr
Experimental bombardments	31.2 hr
Operational total	<u>1,250.5 hr</u>
Outage time	110.3 hr
Available time	<u>1,360.8 hr</u>
Shutdown	831.2 hr
Holidays	16.0 hr
	<u>2,208.0 hr</u>

An operating efficiency of 91.9% was maintained throughout this quarterly period.

HEAVY-ION LINEAR ACCELERATOR

Chester M. Van Atta in charge

DEVELOPMENT AND OPERATION

Edward L. Hubbard

- Aug. 1 to Aug. 3. During the days the machine was shut down to permit installation of a permanent power supply for the drivers for the main rf amplifiers, installation of power equipment for an additional rf amplifier, and installation of equipment needed to increase the pulse rate. Evenings the accelerator was operated at a pulse rate of 2 per sec, producing an average beam current of .01 meter  $\mu$ a of nitrogen ions.
- Aug. 5 to Aug. 16. Installation of the cooling system for the oil in the transformers in the power supply for the rf system prevented any operation. This shutdown was also used to install stand-by connections from the city water system to the vacuum pumps and refrigerators, to flush the water jackets on the drift-tube stems to prevent further corrosion, to do maintenance work on the cooling tower and water pumps, and to continue debugging the refrigerators.
- Aug. 17 - Sept. 10. Days were used for installation of electrical equipment and plumbing for the additional rf amplifier, installation of plumbing for the air dryer for the injector, work on the refrigerator system and installation of shielding. Evenings were used in debugging the operation at increased pulse rate and studying the focusing of the beam. At 10 pulse per sec, .06 meter  $\mu$ a of nitrogen ions was available. Since September 4 most of the beam measurements have been made on the beam that goes through the 3-by-7-mm hole in the target used in the heavy-element chemistry experiments. About 1/3 of the total beam now goes through this aperture.
- Sept. 10. - Nov. 1. In general mornings were used for installation and maintenance work, afternoons for debugging the changes made during the morning and tuning up the machine, and evenings for heavy-element chemistry experiments. Installation of the air dryer for the injector and the fourth amplifier was completed. The beam was increased by a factor of 2 1/2 by a pair of strong-focusing magnets between the injector and the pre-stripper tank. The use of tuners to straighten the rf mode in the poststripper cavity increased the beam by 50%. Addition of a buncher increased the beam by a factor of 3. These changes plus added experience in tuning the accelerator resulted in a carbon-ion beam of 0.4 meter  $\mu$ a through the 3-by-7-mm aperture in the chemistry target. With this aperture removed, the total accelerated beam was 1.5 meter  $\mu$ a or 0.25 particle  $\mu$ a of carbon ions. Carbon-13 ions were accelerated for the first time, and a beam current of 0.03 meter  $\mu$ a was obtained in the chemistry target.

In addition to the heavy-element chemistry work, bombardments were started for experiments on neutron production by heavy ions, elastic scattering of heavy ions, and medical physics

## LINEAR ACCELERATOR

James Donald Gow in charge

### OPERATION

The linear accelerator operated normally up to October 15; it was used primarily for the p-n neutron-spectra experiment being run for Moyer's group. A 3-week shutdown was necessary in August because of mechanical failure of one of the Van de Graaff textolite terminal supports. The failure was identical in type to previously reported failures, and complete disassembly and reassembly of the Van de Graaff high-potential structure was necessary. No difficulty was experienced in returning the machine to operation after replacement of the textolite.

On October 15, operation for research ceased preparatory to physical transfer of the accelerator to the University of Southern California. The present spark-gap switching will be replaced with an ignition system, and radio-frequency shielding will be installed and both changes tested before the machine is dismantled for shipment.

## SYNCHROTRON

Rudin M. Johnson in charge

The synchrotron was used for physics research experiments through the month of August and the first half of September. During the latter half of September and much of October the synchrotron was not used for physics experiments because of low beam intensity and a minor overhaul of the conducting silver coating of the vacuum chamber. The silver coating had hardly been touched in two and one-half years of operation. It was damaged in July during an attempt to inject beam into the machine by using two guns together.

The construction of the linac No. 2 vault and Bldg. 68 mezzanine was finished in September, permitting resumption of linear accelerator experiments. The mezzanine provides much-needed offices and an increase in research setup area for physics research personnel. Improved areas are provided for operating personnel and for synchrotron-development programs.

The linac No. 2 has been used by Donald Fluke for bombardment of enzymes, and by Richard Lemmon and Robert Lindblum for bombardment of choline derivatives and deuterated choline chloride. The linac No. 1 is being overhauled and a new wave-guide accelerator and vacuum system are being installed.

Information Division  
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