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PHYSICS DIVISION QUARTERLY REPORT

FEBRUARY, MARCH, APRIL 1957

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PHYSICS DIVISION QUARTERLY REPORT

February, March, April 1957

May 13, 1957

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PHYSICS DIVISION QUARTERLY REPORT

February, March, April 1957

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Radiation Laboratory
University of California
Berkeley, California

May 13, 1957

GENERAL PHYSICS RESEARCH

PHYSICS RESEARCH

Luis W. Alvarez in charge

LIQUID HYDROGEN BUBBLE CHAMBERS

Operation and Development

James Donald Gow

10-Inch Chamber

Owing to the Bevatron shutdown there was no operation of the 10-inch chamber during February, March, or April. Since it was intended to replace the 10-inch with a 15-inch chamber, no modification work was done. In mid-April we decided to use the 10-inch chamber on the first run to be made when the Bevatron returns to operation.

Lower background appears essential for the next run, which will be a continuation of the 1.4-Bev/c K^- experiment. The energy of the π mesons will be reduced to approximately 1.1 Bev to operate in a region that is more sensitive for coplanarity determination. A complete concrete shield was designed to fit around the chamber magnet, and the necessary blocks were purchased.

15-Inch Chamber

The majority of the mechanical parts of the chamber were completed, and assembly has proceeded throughout the period as parts became available. The only difficulty encountered was in hard-soldering a thin stainless steel beam-entrance window into the chamber body. An acceptable alternate solution using "Heliarc" welding was developed, and the window has passed hydrostatic tests. Because of the decision to make the Bevatron run with the 10-inch chamber, a delay of 4 to 5 weeks in completion of the 15-inch is expected. The completion date should fall in early August.

4-Inch Chamber

The 4-inch chamber was modified to use a fast recompression system similar to that used on the 10-inch chamber. This modification was necessary in order to reduce the excessive hydrogen consumption encountered with the high-pulse-rate running needed for the neutron-energy-distribution experiment. The fast-recompression system operated as predicted, and the chamber has been used almost continuously as a proton-recoil neutron spectrometer. The neutron experiment, using the 32-Mev linear accelerator, is being done as a "service function" for Moyer's Research Group.

72-Inch Chamber

The magnet core has been delivered and the lower magnet coil is complete. A contract for providing the chamber body casting has been let and the chamber body will be delivered in June. Parts for the magnet carriage have been finished and the assembly work is in progress.

Optical measurements on the Jena 5-inch window have been completed, and the window is found to be well within specifications. Although the flatness is only ± 0.020-inch over the surface, the optical corrections due to this warp are negligible. Consideration is being given to grinding the surface to a flatness of ± 0.001-inch and repolishing. This may be required to prevent clamping and sealing difficulties. Test work and calculations relating to this problem are under way.

A contract for fabrication of the liquefier has been let. At this time the design of the instrument is complete except for very minor details. The engineering group is primarily involved in supervising the fabrication and assembly of the equipment and the solution of fabrication problems when encountered.

Construction work on the building has started, and completion is scheduled for early in 1958.

Data Reduction

Hugh Bradner

4-Inch Chamber

Graduate students under Dr. Moyer have continued to use the 4-inch chamber as a neutron spectrometer at the linear accelerator. Analysis of their data is being carried out by their group, using a modified Benson-Lehner "Oscar" digital coordinate reader.

10-Inch Chamber

Measurements of the μ-meson ranges in the decay π-mu-electron events have been completed. This experiment gives a good range-energy relation for charged particles in the hydrogen bubble chamber, and will furnish a better value for the density of liquid hydrogen than can be computed from the thermodynamic information on hydrogen.

All the film obtained in the experiment on K^- interactions at rest has been doubly scanned and all the interactions have been measured. Results of the analysis are summarized in the section on hydrogen bubble chamber physics. The K^- events have been analyzed by graphical methods, using templates, and by digital-computer methods, using the "Frankenstein" projection microscope. Comparison of these analyses has revealed some weakness in the IBM analysis program for determining the intersection of tracks. The subjective evaluation of track positions is sometimes more accurate than the straightforward computation of intersection between two tracks that have been measured separately. Techniques of improving the accuracy of the digital program are being studied and some improvements have been made in the IBM analysis program which now make the digital accuracy at least as good as the graphical technique in all cases.

More than 2000 π^- interactions were accumulated in the 1.1-Bev/c experiment before the termination of the run due to Bevatron breakdown. Approximately 300 of these interactions have been measured on the 35-mm projection reader.

The basic geometrical program "Hydro 2," for obtaining direction cosines, momentum components, and coordinates from all tracks with the two-lens cameras on the 10-inch bubble chamber, has been completed and is working satisfactorily.

Two programs for momentum and energy balance and coplanarity have been started for use on the 1.1-Bev/c π^- experiment scheduled to begin approximately June 1.

15-Inch Chamber

Modifications of the "Hydro 2" and "Hydro 1" programs for determining momentum, components, direction cosines, and coordinates in the 15-inch bubble chamber have been begun.

72-Inch Chamber

A program for the very complicated corrections in the geometrical analysis of pictures from the big bubble chamber has been undertaken. We do not expect to complete this program before the end of 1957.

Detailed designs of the precision data reader for the big chamber are under way. This reader will be constructed at the Radiation Laboratory.

Tests of the wide-angle Dagor lenses for use with special 70-mm cameras have been completed. The lenses show a 14-line-per-mm resolution, 35° off axis, at f/45. This appears to be sufficient for the intended use, but test photographs of a mock-up chamber with bubbles will be taken to determine the appearance of the image to be expected on the big chamber.

Detailed design of the special cameras is under way.

Physics Research With Liquid Hydrogen Bubble Chambers

Luis W. Alvarez and group

The 4-inch chamber was operated by this group for the benefit of the Moyer and Kenney groups, who present their results elsewhere in this report. Since the Bevatron was not available, the 10-inch chamber was not used, but interpretations of the data were carried out as follows.

1. Further Results of K^- Interactions in Hydrogen (Luis W. Alvarez, Hugh Bradner, Paul Falk-Vairant, James Donald Gow, Arthur H. Rosenfeld, Frank Solmitz, and Robert D. Tripp)

The 250 K^- mesons that were observed to interact in the 10-inch hydrogen bubble chamber have now been analyzed. The lifetimes of the various hyperons are established with more precision. They are

$$\tau_{\Sigma^+} = 0.70 \pm 0.10 \times 10^{-10} \text{ sec},$$

$$\tau_{\Sigma^-} = 1.60 \pm 0.20 \times 10^{-10} \text{ sec},$$

$$\tau_{\Lambda} = 3.1 \pm 0.5 \times 10^{-10} \text{ sec}.$$

No evidence is found for the existence of two lifetimes for any of the hyperons.

There appear to be fewer Λ produced directly in K^- capture than were reported previously. Of the 54 events observed to decay via $\Lambda \rightarrow p + \pi^-$, 44 ± 6 arise from Σ^0 and 10 ∓ 6 from Λ produced directly. Also, 122 Σ^- and 63 Σ^+ were observed.

The angular distribution of Σ decays on the basis of the analysis of about half the present number of events appeared at first to be anisotropic, indicating a Σ spin greater than 1/2. This anisotropy has now disappeared, so that we no longer have any indication for higher spin. Likewise no fore-aft asymmetry is observed. The presence of such an effect would call for the existence of parity doublets.

For those K^- which interact in flight we find a cross section of 54 ± 24 mb for elastic scattering and 110 ± 34 mb for Σ^+ and Σ^- production combined. The analysis of the up-down asymmetry of Σ decay with respect to the normal to the plane of production (defined as $\vec{n} = \vec{p}_K \times \vec{p}_\Sigma$) gives some evidence--though based on poor statistics--for nonconservation of parity in Σ decay. For the Σ^- decays, seven pions are emitted into the lower hemisphere, while two decay into the upper hemisphere. Σ^+ decays yield 3 and 0 respectively. Only events with $p_K > 100$ Mev/c were chosen, so as to assure sufficient p-wave contribution to the incoming channel.

2. Catalysis of Nuclear Reactions by μ^- Mesons (Marcello Cresti, Klaus Gottstein, Arthur H. Rosenfeld, and Harold K. Ticho)

In this quarter extensive measurements have been carried out on the nuclear reactions catalyzed by μ mesons, and the results are shown in the following table:

Deuteron concent(%)	% of internal conversion of μ	% of μ-e decays with gap 0.3	% of converted μ's with gap 0.3	% of μ transf. on deut.	Av gap lgth
0.02	0.7 ± 0.2	17.1 ± 1.6	31 ± 16	55 ± 29	0.6
0.3	2.3 ± 0.2	24.2 ± 2.6	32 ± 6	76 ± 16	0.6
4.2	2.5 ± 0.4	1.6 ± 0.5	---	---	---

From measurement of the frequency of occurrence of gaps at the endings of the μ in the μ-e decays and in the "rejuvenations," and from the number of the latter, some conclusions can be drawn on some of the parameters involved in the process.

We found that in liquid hydrogen with a deuteron concentration of 0.02 atom percent, about 50% of the stopping μ mesons are transferred on a deuteron, and that this figure becomes ~80% when the deuteron concentration is increased to 0.3%. From the above value of 80%, and from the observed number of internal conversions in the 0.3% deuteron concentration (2.3 ± 0.2 %), and by making use of simple hypotheses, we have been able to set limits to the time taken for the formation of a PμD molecule from a Dμ system and an H atom. These limits are 10^{-8} and 10^{-5} sec, and, depending on the value of this time, the frequency of internal conversion of the μ, over the total number of He^3 formations, varies from 5% to 60%.

3. Associated Production of Strange Particles by 1.5-Bev π^- Mesons (Marcello Cresti, Frank S. Crawford, Lazare Goldzahl, Myron L. Good, Klaus Gottstein, M. Lynn Stevenson, and Harold K. Ticho)

At the time of the Bevatron shutdown the 10-inch chamber had been used for 2 days in a study of the reactions

$$\pi + p \rightarrow (\Lambda \text{ or } \Sigma) + K.$$

The π^- had a 0.1% component of K^-, whose interactions with protons could also be studied. One interaction $K^- + p \rightarrow \Sigma^+ + \pi^-$ was seen, and roughly 100 strange particles were made. The experiment will be resumed as soon as the Bevatron is available.

4. Search for Particles of Mass 500 m_e (Marcello Cresti)

In the second half of December 1956 the 10-inch liquid hydrogen bubble chamber was used to search for the particle of mass about 500 m_e which, according to Alikhanyan, may exist in cosmic radiation. No such particles have been found. An upper limit for the production cross section is

$$\frac{d^2\sigma}{dp\ d\omega} \lesssim 1.4 \frac{\exp[(1.7/\tau_2)10^{-8}]}{1-\exp(-10^{-9}/\tau_1)} 10^{-33} \frac{cm^2}{Mev/c\ steradian}$$

at 35° and 455 Mev/c, where we assumed that these particles have a mean life τ_2 and come from the decay of heavier particles, having a mean life τ_1, produced in the target. For understanding the meaning of the above result, we can say that, taking $\tau_1 \lesssim 10^{-9}$ sec (with $\tau_1 \gg 10^{-9}$ sec no particles of 500 m_e could have reached the bubble chamber in our setup), and taking $\tau_2 \gtrsim 10^{-8}$ sec, which seems to be the lower limit for the mean life of these particles as given by Alikhanyan, the value of the cross section becomes smaller by two orders of magnitude than that for K^-'s accepted by the same channel (0°, 455 Mev/c).

MISCELLANEOUS RESEARCH

Neutral K Mesons

Myron L. Good

Some thought was given to the question of whether there is any evidence for or against conservation of CP (Charge conjugation times parity) in the K^0 - $\bar{K}^0$ complex. If neither C nor P nor T (nor CP) is conserved, one still has the system of two distinguishable particles (K^0 and $\bar{K}^0$) coupled together by common decay modes. The separation into a long-lived and a short-lived component still occurs, as discussed by Lee, Yang, and Oehme. (The assumption of invariance with respect to CPT (T = time reversal) is made, and is the basis of most of their results.)

Their expressions were re-examined in the light of the fact that one decay mode (the two-pion mode) has an overwhelmingly greater transition rate (from, say, a K^0) than all other modes.

It then turns out that the following predictions can be made:

(a) One lifetime will be much longer than the other. (Call the ratio of lifetimes ϵ; then we have $\epsilon \ll 1$.)

(b) The long-lived component will hardly ever decay into two pions.

$$\left(\text{Branching ratio, } \frac{\text{Two pions}}{\text{Total decays}} \simeq \epsilon .\right)$$

This statement must be qualified, but the necessary conditions for it to hold may well be fulfilled.

(c) The e^+/e^- ratio or μ^+/μ^- ratio of the decay modes $\pi^\pm\mu^\mp\nu$ and $\pi^\pm e^\mp\nu$ will be essentially 1. (The deviation from 1 is of order ϵ).

Since these are just the statements that conservation of CP enables one to make, the K^0-$\bar{K}^0$ complex presents no evidence for or against conservation of CP.

The third statement is most interesting, since the fragmentary experimental evidence so far seems to contradict it. These results, if confirmed, might be evidence against CPT invariance.

These results have also been obtained independently, in whole or in part, by Lee and Yang and by Murray Gell-Mann. Therefore, they will not be published separately but will be incorporated in substance in the review article by Gell-Mann and Rosenfeld, now being written.

PHYSICS RESEARCH

Walter H. Barkas in charge

STRANGE-PARTICLE RESEARCH

Walter H. Barkas, Walter F. Dudziak, Peter C. Giles, Harry H. Heckman, Fred W. Inman, Conrad J. Mason, Norris A. Nickols, and Frances M. Smith

In the emulsion stacks exposed in October 1956 we have now studied more than 3000 negative K mesons. Along-the-track scanning has been employed. Data have been obtained in the following categories: mean free path for inelastic K^- collisions; elastic cross section for K^--p collision; cross sections for $K^- + p \rightarrow \Sigma^{\pm} + \pi^{\pm}$; probability of capture by proton at rest; K^--capture star characteristics; K^- mean life; K^- decay modes; Σ^- and Σ^+ production probability and energy spectra from K^- interactions with emulsion nuclei; Σ^- and Σ^+ lifetimes; Σ^+ decay branching ratio; Σ^- interactions with nuclei; Λ^o production; K^-, Σ^+, Σ^-, and Λ^o masses; hyperfragment production; and binding energies of hyperfragments.

ANTIPROTON INTERACTIONS IN EMULSION

Harry H. Heckman and Frances M. Smith

The scanning in our latest antiproton emulsion stack for the purpose of locating antiproton tracks has been completed. We have tentatively identified 34 such tracks as those of antiprotons. Of these, 18 came to rest after traversing a mean range of 13.1 cm, which corresponds to an antiproton of momentum 700 Mev/c; and 16 interacted in flight. In the energy interval 20 to 200 Mev (0.18 to 10.3 cm range) the mean path was observed to be 17 ± 4 cm. A detailed study of the annihilations is now in progress. To date, 16 interactions have been analyzed. The mean number of charged pions per star is 2.4 ± 0.5. No annihilation giving rise to more than four charged pions has been observed thus far. The mean kinetic energy in the pions is 156 Mev; the most energetic pion observed had about 450 Mev (kinetic). One secondary prong was identified as a K meson by its rate of change of ionization and its $p\beta$ (Mev/c) vs ionization. The annihilations have given no concrete evidence for hyperon production.

HIGH-ENERGY BETA DECAY

James Vedder and Walter Dudziak

We have completed the laboratory phase of the experiment in which a study was made of the lifetimes and energy spectra of the high-energy beta emitters B^8, Li^8, N^{12}, and B^{12}. The studies have been made with a spiral-orbit spectrometer, using the proton linear accelerator to create the short-half-life activity. In addition, several weeks were spent studying various focusing properties of the spectrometer. Such studies included the effect on the energy spectra of proton beam misalignment (with the spectrometer axis of symmetry), and also the effect of misalignment of counter slit position. The data are now being processed.

Numerous radial magnetic field measurements were made with a constant-temperature heated bismuth probe. This will check our previous energy calibration of the spectrometer.

PHYSICS RESEARCH

Robert W. Birge in charge

K^+ SCATTERING FROM NUCLEI

Leroy T. Kerth, Thaddeus Kycia, and Lud van Rossum

Analysis of data taken in a counter experiment at the Bevatron during December has been completed. The attenuation cross section and the differential scattering cross section in one angular interval for K^+ mesons of 192 Mev were measured. The targets were carbon, aluminum, copper, silver, and lead. The cross sections were analyzed in terms of the optical model to determine the real and imaginary potentials. The average real potential was found to be 24 Mev. The mean free path in nuclear matter was found to be consistent with a K^+ nucleon-scattering cross section of about 10 millibarns. Some evidence was found for a Z dependence of the mean free path in nuclear matter. Details of this analysis are contained in a separate report.[1]

CHARGE EXCHANGE OF K^+ MESONS

Robert W. Birge, Marian Whitehead, and Robert Lanou

Work has been continuing on the improvement and preparation of the multiplate cloud chamber, counter telescope, and associated equipment to be used in an experiment on the decay modes and interactions of neutral K mesons that have been produced in the charge exchange of K^+.

Planning was also begun on a cooperative experiment, as an extension of the experiment above, with Wilson Powell and William B. Fowler. It will use a large propane bubble chamber with magnetic field in place of a multiplate cloud chamber. Design work has been initiated on data-reduction and analysis equipment for this experiment.

ANTIPROTON SCATTERING

Jack Sandweiss

In order to interpret the data from elastic scattering of $\bar{p}$ in emulsion, the expected scattering distribution from various models of the $\bar{p}$-nucleus interaction are being computed. These calculations utilize the W.K.B. approximation for the phase shifts, and the IBM 650 to sum the partial waves and average over emulsion contents and $\bar{p}$ energy. The only model examined in detail to date is the "charged absorbing sphere" model. This agrees quite well with the data except in the 2-to-5° region, where the model predicts somewhat more scattering than is observed. The calculations will also be made for the "charged diffuse-edge absorbing sphere" model, and for the model by Duerr and Teller. Finally, the $\bar{p}$

[1] Leroy T. Kerth, The Total Cross Sections for 190-Mev Positively Charged K Mesons in Complex Nuclei (Thesis), UCRL-3747, April 1957.

emulsion scattering data previously obtained in this experiment have been lumped with the data of Gerson Goldhaber from a stack exposed in the partially separated $\bar{p}$ beam. A total of 11.74 meters of $\bar{p}$ track has been scanned, yielding approximately 65 scatters with projected angle greater than 2°.

THEORETICAL GROUP

David L. Judd

"Strange" Particles

A general formalism describing the angular correlation and polarization effects in the production and subsequent decay of particles of arbitrary spins has been developed. It has been specialized to the cases of the production and decay of particles of spins 1/2 and 3/2. Various production mechanisms have been considered, and expressions for the angular distribution and polarization of the decay products have been reduced to tractable forms involving the physical vectors of the problem and a minimal number of parameters describing the production and decay interactions. Experimental methods of determining these parameters are being investigated. (Richard Spitzer and Henry P. Stapp)

When K^- particles are captured from rest in emulsions, estimates show that the capture tends to occur from a fairly high angular momentum state, $\ell = 5$ or 6. Thus it is most likely that these particles will be captured by single nucleons far out in the tail of the nuclear-density distribution. The resulting final states are being examined. (Stephen Gasiorowicz, with Malvin A. Ruderman and Julie Wagoner of the Physics Department)

A study of the associated production of K particles and hyperons in high-energy pion-nucleon and nucleon-nucleon collisions is in progress. An attempt is being made to formulate a theory that will correlate the early experimental observations, such as the forward preference of Σ^- and the backward preference of the Λ^0 particles produced in π^- - p collisions. To this end a linear integral equation for the amplitude describing the associated production in a pion-nucleon collision has been set up using the method of Low. The kernel of this equation is the pion-nucleon scattering amplitude. A paper is being prepared on this subject. (Saul Barshay)

A study has been carried out for the τ-θ problem along the lines suggested by Trieman and Wyld, showing the difficulty of this solution. Various possibilities for detecting parity nonconservation in hyperon decay are now being examined. (R. R. Gatto)

An attempt to calculate Σ production and scattering by protons has been made using the field theoretical perturbation formalism. This was found to be unsatisfactory owing to the strong coupling. (Zaven Guiragossian)

A possibility of obtaining an upper limit for the Σ spin from K^--absorption data is being investigated. (R. R. Gatto)

Symmetries

Experimental consequences of the various symmetry properties still permissible in the weak interactions are being investigated. A decision between the validity of the Luders theorem and invariance under charge conjugation (two mutually exclusive possibilities) can be obtained if the relative spin directions of the μ^+ and μ^- from $\pi^\pm$ decay are measured. Charge-conjugation invariance implies the equality of these spins, whereas the Luders theorem requires that the spins be oppositely directed. Similar conclusions may be obtained from the decay of $\mu^\pm$ and from the decay of the long-lived neutral K particle. (Henry P. Stapp)

The general expression of the electron distribution in mu-meson decay is given by a three-parameter formula. In the usual four-component theory of the neutrino, it is possible for these three parameters to have various values. In the two-component theory of the neutrino with the interaction Hamiltonian density of the type $(e, \mu)(\nu, \nu)$, two of these parameters must have definite values. In addition, if we use the interaction Hamiltonian density of the type $(e, \nu)(\nu, \mu)$ and restrict the type of coupling (for example, only vector coupling), all three parameters must have definite values. Moreover, if the conservation of lepton number is assumed, the positron emitted in μ^+ decay is completely polarized in the direction antiparallel to its momentum and the electron in μ^- decay is completely polarized in the direction parallel to its momentum. This polarization is independent not only of the energy but also of the angle of emitted particles, if the mass of the electron is small compared with the electron momentum. The measurement of longitudinal polarization of electrons or μ mesons will be useful for considering the conservation of lepton numbers. Calculations leading to these results are presented in a separate UCRL report[1] and in the Proceedings of the Seventh Rochester Conference. (Tsuneyuki Kotani)

Some additional work was done on the relation between covariance and conservation laws. The nonconservation of parity may be expressed by means of an additional degree of freedom for the system, which is the analogue of spin in the case of nonconservation of angular momentum (defined only as orbital angular momentum). The generalized parity (the analogue of total angular momentum with spin) is of course conserved. (Maurice Neuman)

Weak interactions are being studied, particularly π-meson and μ-meson decays. The implications of parity nonconservation in regard to the polarization of the decay products and their momentum spectra are being considered. (Owen Eldridge)

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[1] Tsuneyuki Kotani, A Possible Test of a Two-Component Theory of the Neutrino, UCRL-3715, March 1957.

Some studies have been made of possibilities of determining whether time-reversal invariance must be abandoned. (1) It was found that this invariance is not valid if, in μ-meson decay, any transverse polarization of the emitted electrons is detected. This work was described in a separate report.[2] (2) The present experimental data on positron angular distrubutions in the beta decays of oriented Co^{58} and Co^{56}, together with the electron-neutrino angular correlation in the decay of Ne^{19}, may imply a violation of time-reversal invariance. This conclusion cannot yet be definitely drawn without more accurate experimental results, especially those involving pure Fermi Transitions, for example, A^{35}, A^{36}, and O^{14}. (3) If parity is not conserved in beta decay, polarization of the electrons results. There are some correction terms which come about because of Coulomb distortions of electron wave functions and which indicate noninvariance with respect to time reversal. Workers at several laboratories are planning to measure these correction terms. They have been calculated and reported.[3] (Tsuneyuki Kotani)

Dispersion Relations

A paper entitled "Uniqueness of Solutions to Dispersion Relations for Potential Scattering" has been completed and submitted for publication. It shows by explicit examples that even for a well of finite range the dispersion and unitarity relations do not define a unique scattering amplitude, so that they do not contain all the information that is derivable from the Schrödinger equation. (Stephen Gasiorowicz, with Malvin A. Ruderman of the Physics Department)

An attempt has been made to set up a dispersion relation for the anplitude describing the production of a pion in a pion-nucleon collision. Particular attention is being paid to exhibiting the role of a possible meson-meson interaction in such a relation. (Saul Barshay)

A study of the Chew-Low dispersion formalism has been undertaken with the object of calculating the anomalous magnetic moment of a nucleon and the structure of the bare nucleon. (Zaven Guiragossian)

Statistical Theories

A unified and mathematically consistent treatment of the statistical approach to high-energy events has been developed. Linear and angular conservation laws as well as quantum effects arising from indistinguishability of particles are fully taken into account. A relativistic thermodynamic approximation based on a "temperature" four-vector and a scalar entropy has been investigated and found suitable for practical computation in the high-energy limit. (Maurice Neuman)

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[2] Tsuneyuki Kotani, A Possible Test of Time Reversal in Mu-Meson Decay, UCRL-3704, March 1957.

[3] Tsuneyuki Kotani, A Possible Test of Time-Reversal Invariance in Beta Decay, UCRL-3724, March 1957.

A calculation has been carried out on the role of the strangeness-selection rule in thermodynamical theories of multiple production. (R. R. Gatto)

Some preliminary results have been obtained on a strong-coupling approximation to field theory from which the Fermi model emerges as a zeroth-order approximation. More precisely the quantum mechanical transition probability is shown to correspond to a marginal distribution in momentum space derivable from a quasi distribution in coordinate and momentum space of the Wigner type. The classical phase space used by Fermi is the zeroth-order approximation, in powers of Planck's constant, h, to this quantity. (Maurice Neuman)

Nuclear Physics

The possibility of interpreting the experimental results of the anomalous scattering of 22-Mev protons obtained by Bernard Cohen of Oak Ridge by means of a collective radial oscillation, or breathing mode, of the nucleus is being examined. The central region of the nucleus is too rigid to explain either the magnitude of the apparent energy level, or the constancy of this magnitude from nucleus to nucleus. However, the rim or edge region of the nucleus is comparatively compressible, and a rough model of the nucleus consisting of a rigid inner core and a compressible region about the edge does yield results partially in agreement with Cohen's experimental results. Further work in terms of a more realistic model is in progress. (Warren Heckrotte)

The study of zero-energy neutron scattering from a spheroidal potential has been completed, and a paper has been submitted to the Physical Review. (Jack L. Uretsky)

An attempt is being made to explain the radial variation of the imaginary nuclear optical model potential, for low-energy neutrons incident on nuclei, found by Bjorklund and Fernbach at Livermore, as a consequence of the exclusion principle. (Warren Heckrotte)

Work is still in progress on nuclear spectroscopy in the vicinity of the f7/2 proton shell. Its original purpose was to see whether the anomalous ground-state spin (5/2) of Mn^{55} followed in a natural way from the j-j coupling shell model. It was intended that the calculation would be done by assuming a form for the n-p, p-p, and n-p interactions. In the process of analyzing the experimental data, however, it was found possible to carry out the calculation using only empirical values for the two-body matrix elements.

The first step in the revised calculation was to examine the interaction among protons of the f7/2 shell. All the elements whose configuration should be $(f7/2)^n$ protons and a closed neutron shell have

been studied. It was shown that the three lowest excited states of this configuration were the same for n = 2, 4, 6. Then, by making use of certain geometrical relationships, it was possible to predict the energies of the excited states of the configurations $(f_{7/2})^3$ and $(f_{7/2})^5$. The agreement with experiment was considered to be quite good. Since one result of the method was a prediction of the spins of several of the excited states of V^{51} and Mn^{53}, it was deemed worth while to publish the result of this preliminary calculation. Accordingly, a letter has been submitted to the Physical Review.

What is believed to be a new sum rule relating certain nuclear excited states has also been discovered. To give an example, consider two nuclear configurations, of which one has closed shell protons and an even number of neutrons, and the other has the same configuration to which has been added a single proton, of angular momentum j, outside the closed shells. The first nucleus will have a first excited state of angular momentum two, which corresponds to a recoupling excitation of the neutron configurations. In the second nucleus the neutrons may also be excited to a J = 2 state, but now the odd proton can couple to this in 2j + 1 ways (or 5 ways if $j \geq 2$) with resultant angular momentum J_i. The sum rule tells us that if each such state of the second nucleus is weighted by an amount $2J_i + 1$, then the center of gravity of this set of states has the same excitation energy as the 2 state of the first nucleus. It is found that this sum rule gives remarkable agreement with experiment for nuclei in the vicinity of mass number 60, where sufficient experimental information is available. A paper is in preparation. (Jack L. Uretsky, with R. D. Lawson of the Physics Department)

Further numerical calculations on the elastic scattering of deuterons by nuclei are continuing. It has not proved possible as yet to fit the experimentally measured polarization. (Warren Heckrotte)

Miscellaneous

An attempt has been started to find an approximate solution for the phonon-polaron problem by use of the method of moments. The first eight moments have been calculated in a form suitable for numerical computation. The work already accomplished will permit the construction of a quartic equation, and it is hoped that approximations to the two lowest-energy levels will be among the roots. (Francis R. Halpern)

Work on the calculations of the properties of the μ-mesic molecules is continuing. Potentials and exchange potentials for the various isotopic configurations have been calculated. An IBM 701 program will make use of these results to give the wave functions of each of the possible molecular systems. (Stanley Cohen, David L. Judd, and Robert J. Riddell)

The self-consistent relativistic wave functions for several atoms have been obtained. These calculations now include the neutral atomic configurations for Hg, Pt, U, Fe and W. In conjunction with J. Hubbs these self-consistent calculations are being extended to the transuranic elements. (Stanley Cohen)

Theoretical work is continuing on the Bevatron injection system in the interest of maximizing the current available from the present system together with considerations of proposals for major modifications. (John Hiskes)

A paper is in preparation discussing the formulation of Maxwell's equations in rotating coordinates by use of the covariant formalism of general relativity. (Jack L. Uretsky, with John Ise)

Einstein's and Schrödinger's "unified field theories" are being studied with the hope of understanding the linkage of electromagnetic phenomena with matter. (Coates R. Johnson)

A calculation has been done to estimate the minimum electric field necessary to disassociate the H_2^+ ion. The problem arises in considering the maximum energy to which such an ion could be accelerated in a circular machine and remain stable against the $\vec{E} = \gamma \vec{v} \times \vec{B}$ electric field. The ions in the highest vibrational states, representing perhaps a few percent of the total of those from an ion source, appear to be stable for times of order of a second for fields up to 10^8 v/cm, corresponding to a 45-Bev ion in a 15,000-gauss field. The lower vibrational states are stable against even greater fields; however, an accurate estimate for the lower states appears to involve extensive numerical work. (John Hiskes)

Numerical Analysis

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

An IBM 650 program has been written that will find and solve the characteristic equation of any Hermitian matrix of order less than or equal to ten, using the method developed and reported by Frank Halpern.[4] (Marjory Simmons for Francis R. Halpern)

A program has been devised for the analysis of hyperfragment decay reactions. This is part of a complete program for the analysis of hyperfragments in emulsions. (Victor Brady for Walter Dudziak)

An IBM 701 program was written to solve the Schrödinger equation in a study of μ-mesonic molecules. (Victor Brady for Stanley Cohen)

Calculations of orbits in the magnetic fields of cyclotron and Bevatron have been made for various persons using the differential analyzer. (Jonathan Young)

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[4] Francis R. Halpern, The Method of Moments in Quantum Mechanics, UCRL-3721 (rev.), April 1957.

Two programs were devised for the Stores and Accounting Department. One program estimates the average increase in price of inventory items by stratified sampling into section classes. The other uses a Monte Carlo and sampling-experiment approach to predict the number needed on hand of a given item, and when to re-order, based on last year's daily issues. (Michael Lourié for T. P. Hitchcock)

A program to calculate the energy distribution due to ionization loss of a monoenergetic source at various locations within a solid sphere was written for use in resolution studies of the spiral-orbit spectrometer. (Michael Lourié for Walter Dudziak)

A program to evaluate the Michel parameter in μ-meson decay was written. (Michael Lourié for Walter Dudziak)

Masses, kinetic energies, and velocities of Cf^{252} spontaneous fission fragments from time-of-flight data were calculated and tallied, according to prescribed limits, for Robert Pyle. (Robert S. Freeman)

A utility program for the computation of single and double integrals was devised, using fixed-point 650 language and based on Simpson's rule. (Robert S. Freeman for C. A. Tobias)

Preliminary studies for the theoretical calculation of reaction cross sections, for the process in which two neutrons are emitted from a heavy nucleus that has been excited by alpha particles of 20 to 50 Mev, have been made based on the gas model of the nucleus. (Robert S. Freeman for W. Wade)

An IBM 701 program to compute spheroidal wave functions for a specific potential is being written. (David Johnson for Jack Uretsky)

A program to assist in budget analysis by the laboratory administration has been devised and run. (David Johnson for W. F. McNaughton)

Work has continued on the study of the reaction cross section for the emission of two nucleons by a heavy nucleus excited by a proton. (Thomas Clements for Lester Winsberg)

A program to find the best fit of a nonlinear equation in nine variables to an experimentally obtained histogram has been coded for the IBM 650 and is being computed. (Harold Hanerfeld for Lynn Stevenson)

The excited states of nuclei in the vicinity of mass number 50 are being examined with particular attention to Mn^{55}, which seems to have an anomalous ground-state spin, according to the shell model. Computationally, the problem necessitates the calculation of a large number of Racah W coefficients. These coefficients are being obtained in rational form, since this permits the calculations to be largely self-checking. It is expected that, for the convenience of other users, a short table of these coefficients will be published in a laboratory report. (Ardith Kenney for Jack L. Uretsky)

A computation was made to determine the shape of iron required to give the desired field in the cyclotron regenerator. (Ardith Kenney for Ken Crowe)

The data-reduction program designed to determine the momentum, the dip angle, and the azimuthal angle of each track in events in the 10-inch bubble chamber from information taken from the automatic scanning equipment has been completed and operated for a number of events. (Charles Stableford for Luis Alvarez's group)

PHYSICS RESEARCH

Edward J. Lofgren in Charge

EXPERIMENTS ON ANTINUCLEONS AND K PARTICLES

Bruce Cork, William Galbraith, Glen R. Lambertson,
William A. Wenzel, and Charles A. Coombes

Work has continued actively on the preparation of two Bevatron experiments.

The decay of the K meson via the $K_{\mu 2}$ mode will be studied to seek further evidence for nonconservation of parity in weak interactions. A measurement of the degree of polarization of the μ mesons may give information on the spin of the K meson. Positive K mesons emitted at large angles from a target in the west straight section of the Bevatron will be detected electronically and brought to rest just outside the concrete shielding. Mu mesons from the decay will be brought to rest in a sandwich of plastic scintillators and aluminum absorbers. The forward-backward asymmetry of the decay electrons indicates the degree of polarization of the μ mesons. As an aid in this measurement, the use of a weak magnetic field to precess the spin of the μ meson also is contemplated. In a preliminary run, the sandwich will be tested with cosmic-ray μ mesons.

An experiment with antiprotons of momenta below 1 Bev/c is also being designed. Antiprotons from a target in a curved section of the Bevatron emerge at an angle of about 60° with momentum near 800 Mev/c. They would be separated from lighter particles in a (nearly) parallel-plate electrostatic mass separator. Following this, the antiprotons would be channeled magnetically and identified electronically. We propose to measure the cross sections of these antiprotons in several elements, including hydrogen. It is expected that elastic as well as inelastic cross sections will be measured.

The electromagnetic mass separator is nearing completion. It is 20 feet long, and has plane electrodes 8 inches wide. These are 7 inches apart at the entrance end and 2.5 inches apart at the exit end of the separator; if necessary, the electrode separation may be varied. The electrodes may be operated at ± 150 kv, with the possibility of higher voltages if the power supplies become available. A crossed magnetic field may be used to eliminate displacement and deflection of the desired mass component.

THE COAXIAL VELOCITY SPECTROMETER AND A SEARCH FOR PARTICLES OF MASS $500m_e$

Warren W. Chupp, Sulamith Goldhaber, Nahmin Horwitz, and Joseph J. Murray

Construction and high-voltage tests of the coaxial-velocity spectrometer are expected to be complete by June 15, 1957. Its predicted operating characteristics may be found in a separate report.[1]

The first application of the coax is scheduled about 10 weeks after recommencement of Bevatron operation. It will be used to reject pions and transmit particles of approximately 500 m_e in a positive 250-Mev/c beam. Detection of the 500-m_e particles will be attempted with both photographic emulsions and counters. With emulsions it should be possible to push the abundance limit to ~1 per 10^7 pions at the target for a mean life of 10^{-8} sec. Counter detection and a measurement of mean life should be possible for an abundance at the target of about 1 per 5×10^4 pions.

DETECTION OF K-MESIC X-RAYS

Nahmin Horwitz and Joseph J. Murray

A brief account is here given of the nature and status of a future but scheduled experiment for the study of K-mesic x-rays.

Hydrogenlike atoms formed in excited states when K^- mesons stop in matter will de-excite by Auger and radiative processes and eventually be destroyed, usually before reaching the ground state, by nuclear capture of the K meson. In this experiment it is proposed to study the x-ray spectra emitted by K-mesic atoms of various Z. In Fig. 1 are shown the energies (uncorrected hydrogenic) of some of the K, L, M, N, and O series x-rays of Li, Be, B, C, and O, together with an estimate for each transition of W_r/W_a, the ratio of transition probabilities for radiative and absorptive processes, based on an absorption rate for K mesons in nuclear matter assumed to be approximately 100 times that for π mesons. From this information it is expected that no K-series x-rays will be observed; L-series x-rays should be observed in Li and Be; and M, N, O series in B, C, and O, all with energies < 50 kev.

NaI crystal spectroscopy will be used, aided possibly in later phases by x-ray filter technique.

A 420 ± 40-Mev/c K^- beam will be extracted at 0° lab angle from a 2.5° sector target in the north area. K^- mesons will be selected by a counter telescope employing a Cerenkov counter and time of flight. It is expected that five to ten K mesons can be stopped per Bevatron pulse.

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[1] Joseph J. Murray, A Coaxial Electromagnetic Velocity Spectrometer for High-Energy Particles, UCRL-3492, April 1957.

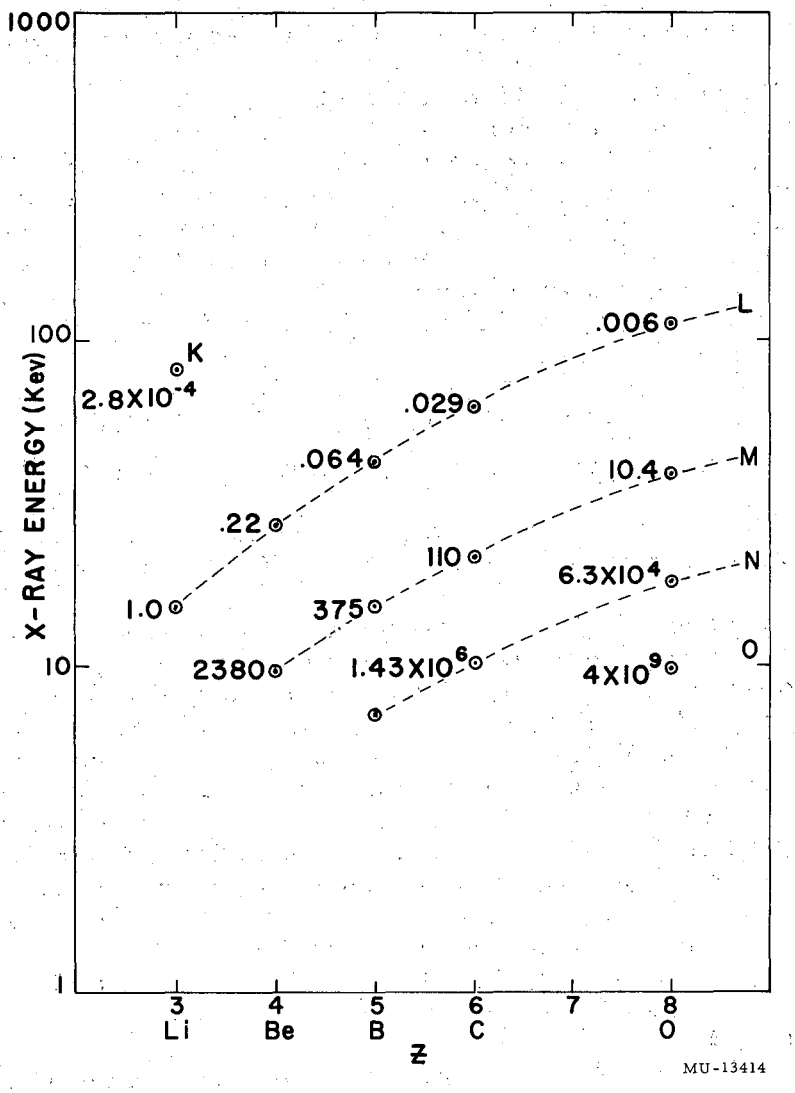

Fig. 1. W_r/W_a for various K-mesic x-rays with maximum initial ℓ, based on absorption rate in nuclear matter = 3.5×10^{23} sec.$^{-1}$ (Rate for π mesons $\sim 2.5 \times 10^{21}$).

A preliminary experiment in which π-mesic x-rays for several Z's were detected has demonstrated the feasibility of the proposed experiment in the Bevatron environment, provided sufficient care is taken to shield the NaI crystals from stray ambient radiation. This is achieved in the setup proposed by using a Pb-Cd-wax house around the NaI plus at least 10 ft of concrete, completely filling a 2 π sector between the NaI and the Bevatron.

A 3-week run has been scheduled to complete a survey of the K-mesic x-ray spectra for the Z values listed. Essentially all the material for the experiment has been assembled and tested.

INTERACTION OF K^+ MESONS IN NUCLEAR EMULSION

Joseph E. Lannutti, Warren W. Chupp, Gerson Goldhaber, and Sulamith Goldhaber

and

G. Puppi and G. Quareni, University of Bologna

Some experimental results of our most recent work on the interactions in flight of positive K mesons in the energy interval 20 to 200 Mev are represented in Figs. 2-9. Emulsion data include combined results of along-the-track scanning of 200 meters at the University of California and 90 meters at the University of Bologna.

We have found 14 new K-H scatters (12 in Berkeley and 2 in Bologna). Combining these with four events by Zorn and two from the Bristol group, and with the 26 events from the 1956 compilation we obtain (a) an essentially isotropic angular distrubution, and (b) an energy-independent value for the cross section $\cong 15.2 \pm 2.4$ mb from 20 to 200 Mev.

In addition we find a change in the ratio of charge-exchange events to non-charge-exchange inelastic events as follows.

Energy	Ratio
20 to 100 Mev	$0.16^{+0.06}_{-0.05}$
100 to 200 Mev	0.24 ± 0.04

The inelastic nuclear cross section increases with energy, but the cross section per nucleon can be considered to remain constant (~ 10 mb) after corrections for Pauli principle and shading. Further corrections may be necessary.

We have also measured the elastic scattering of positive K mesons in complex nuclei and obtained the elastic differential cross section in the energy intervals from 20 to 100 Mev and 120 to 180 Mev (i.e., 150 ± 30). A phase-shift analysis of the data is being carried out by Igo, Ravenhall,

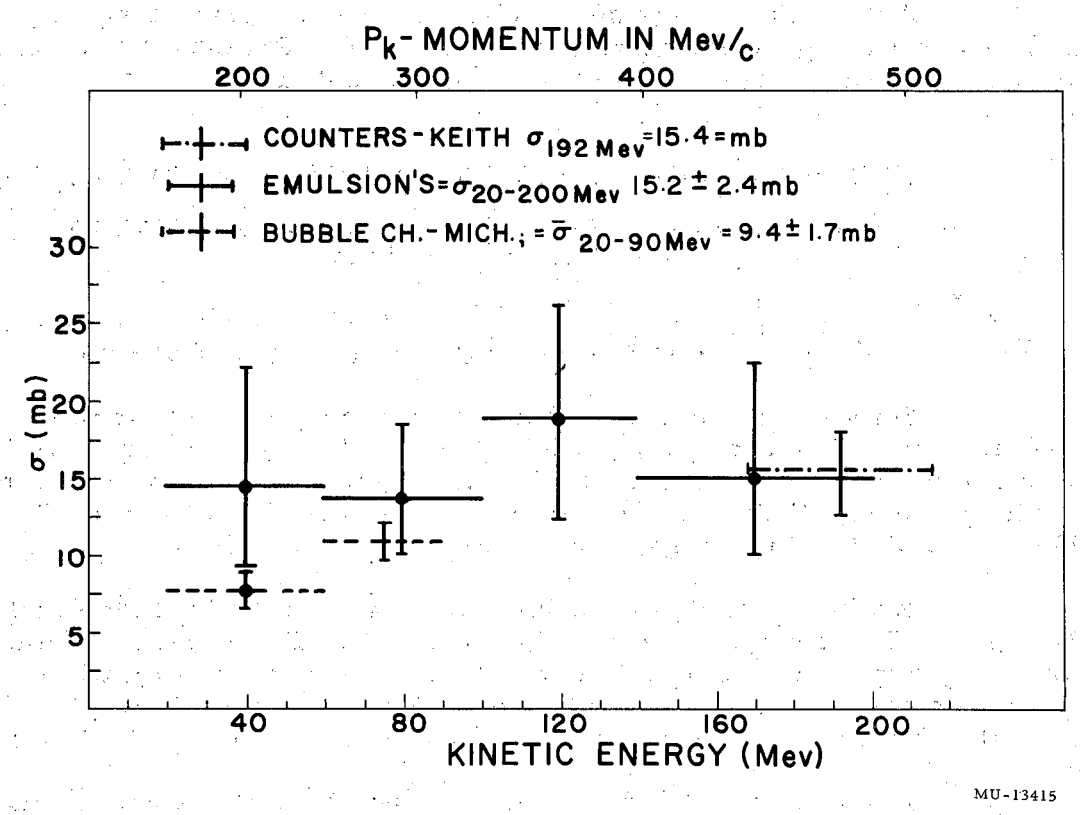

Fig. 2. K^+-p cross section vs kinetic energy. Emulsion data include Göttingen compilation, 1956, 26 events; this work, 10 events; Puppi, 2 events; and Zorn, 4 events. Bubble chamber data from Meyer, Perl, and Glaser. Counter data from Kerth, Kycia and Van Rossum.

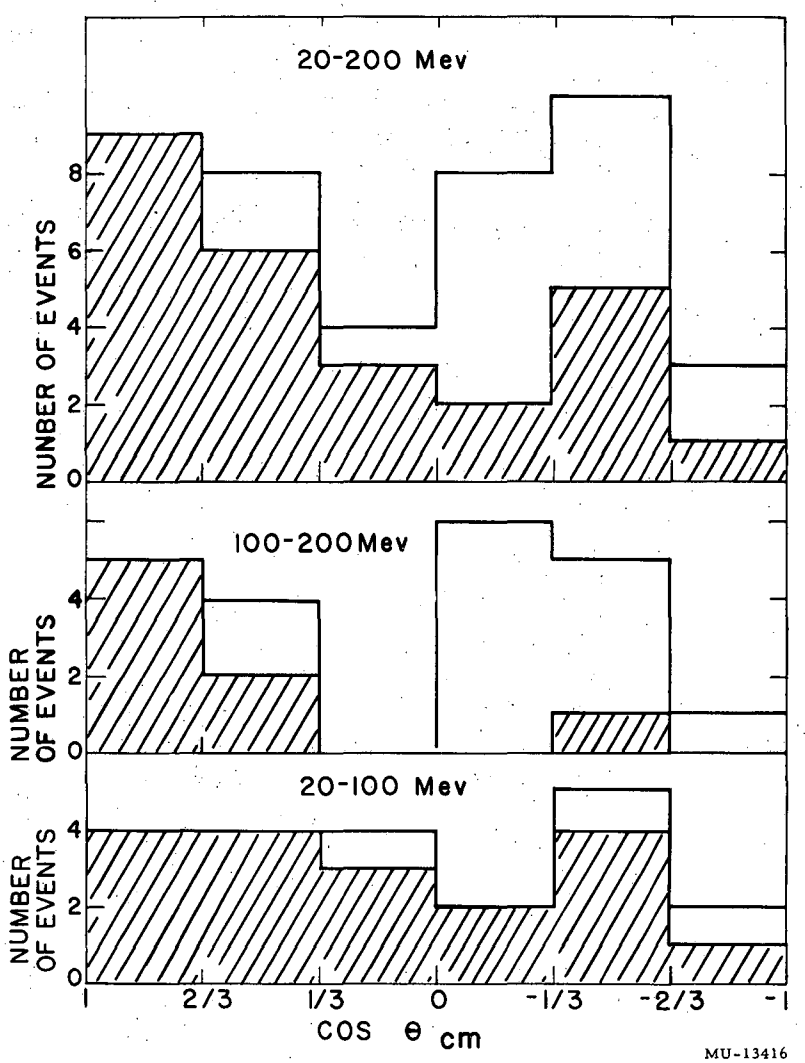

Fig. 3. Angular distribution of K^+-p scatters obtained in emulsion work included in Fig. 1. Cross-hatched events are those of Göttingen compilation of 1956.

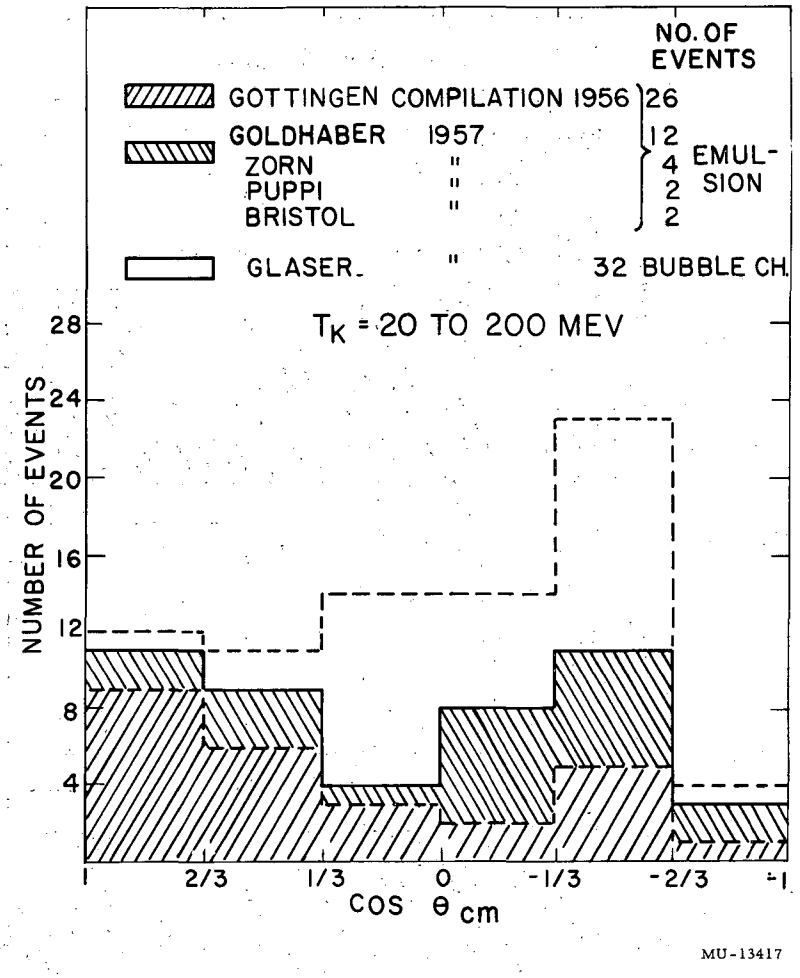

Fig. 4. K^+-hydrogen scatters. Angular distribution of combined emulsion and bubble chamber data for energy interval 20 to 200 Mev. Bubble chamber experimental bias is essentially limited to the first $\cos\theta$ interval only.

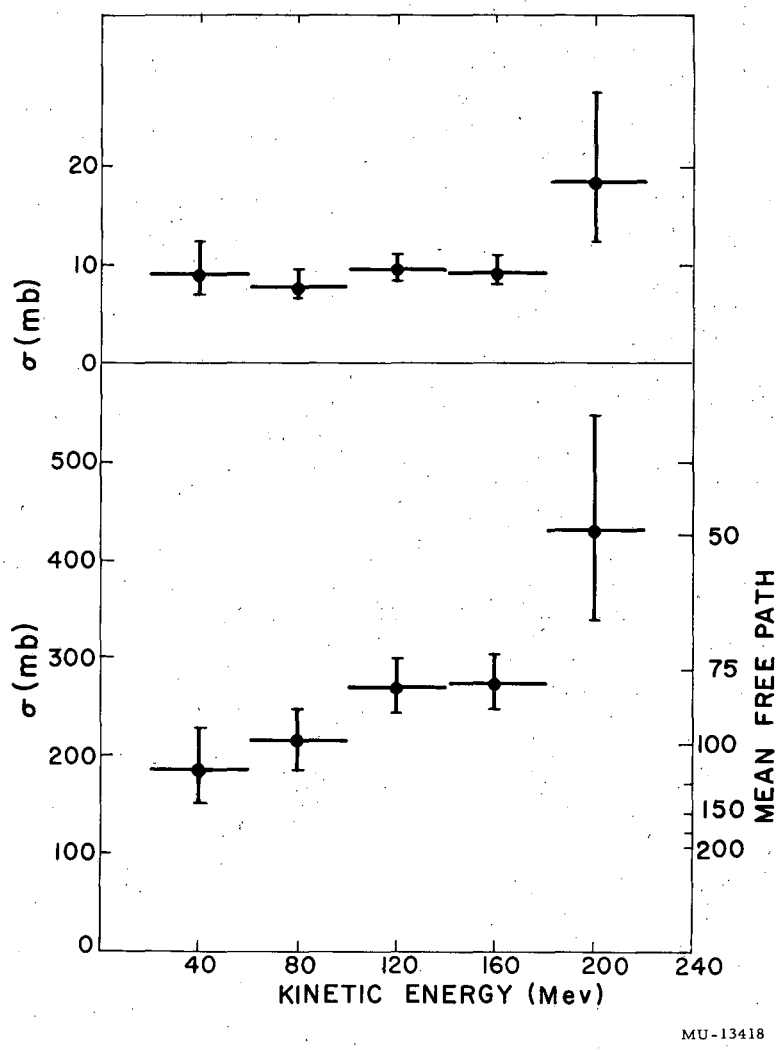

Fig. 5. (a) K^+ cross section in emulsion vs kinetic energy is experimental value based on mean free path for inelastic scatters, i.e., a particle in addition to the K meson is emitted, the energy loss is greater than 10%, or there is a charge exchange. Cross-section computations exclude hydrogen. (b) Data in lower plot (a) are converted to cross section per nucleon vs kinetic energy. Calculation made using optical model and uniform density of nuclear matter to account for nucleon shading. Pauli exclusion-principle correction made for incident energy (i.e., no potential reduction of incident energy is assumed). No correction on cross section was made for Coulomb repulsion or nuclear-potential repulsion. These further corrections would be most effective in raising the low-energy cross-section values.

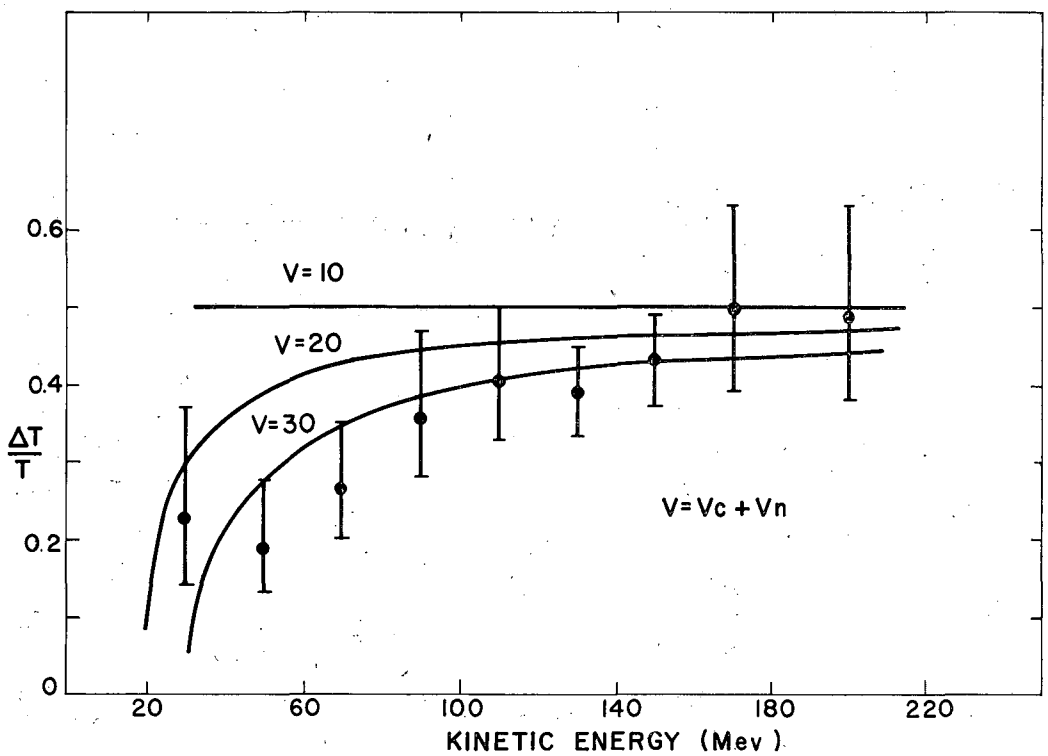

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Fig. 6. Fractional energy loss vs kinetic energy. Includes all inelastic scatters except charge-exchange events. Calculations for curves assumed angular distribution in center of mass was isotropic, and allowance was made for exclusion-principle effects.

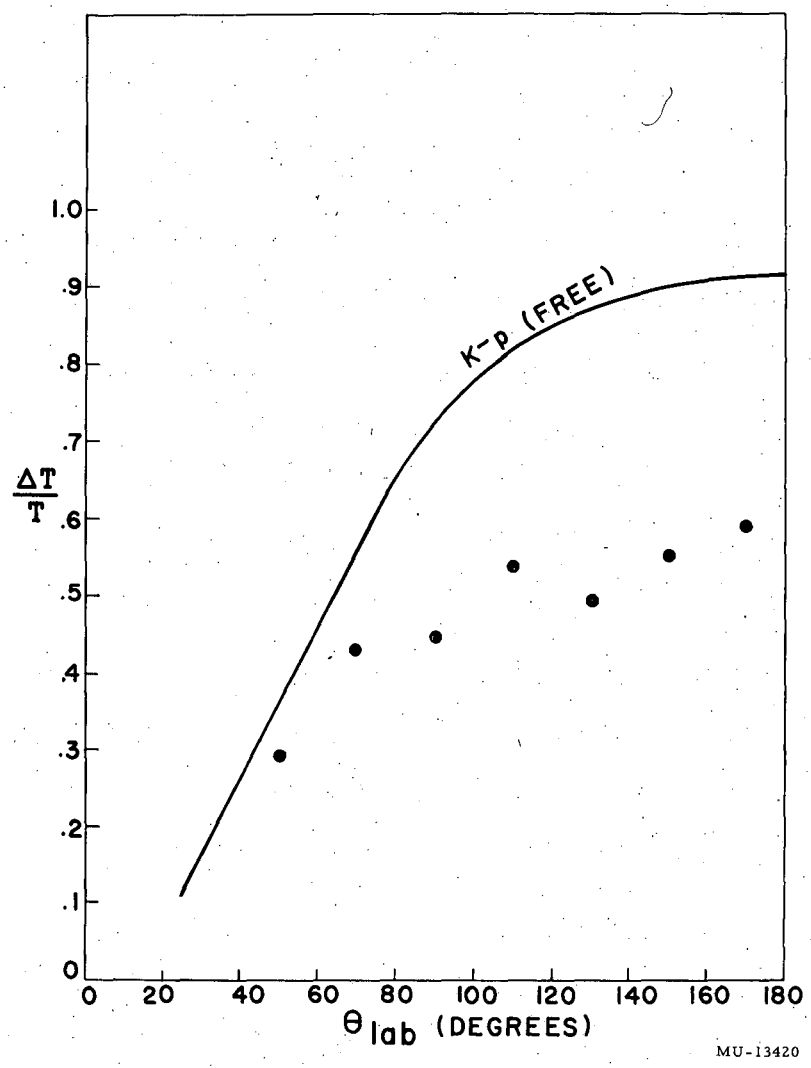

Fig. 7. Fractional energy loss vs K scattering angle for kinetic energy 100 to 200 Mev. $\overline{T}_K$ = 150 Mev. Curve is expected behavior for K scattering from free protons. Points correspond to average of experimental values in 20° intervals of all observed scatters greater than 40°. Assuming single-nucleon scatters as this behavior indicates, the best fit of the experimental points corresponds to expected suppression from a repulsive nuclear potential.

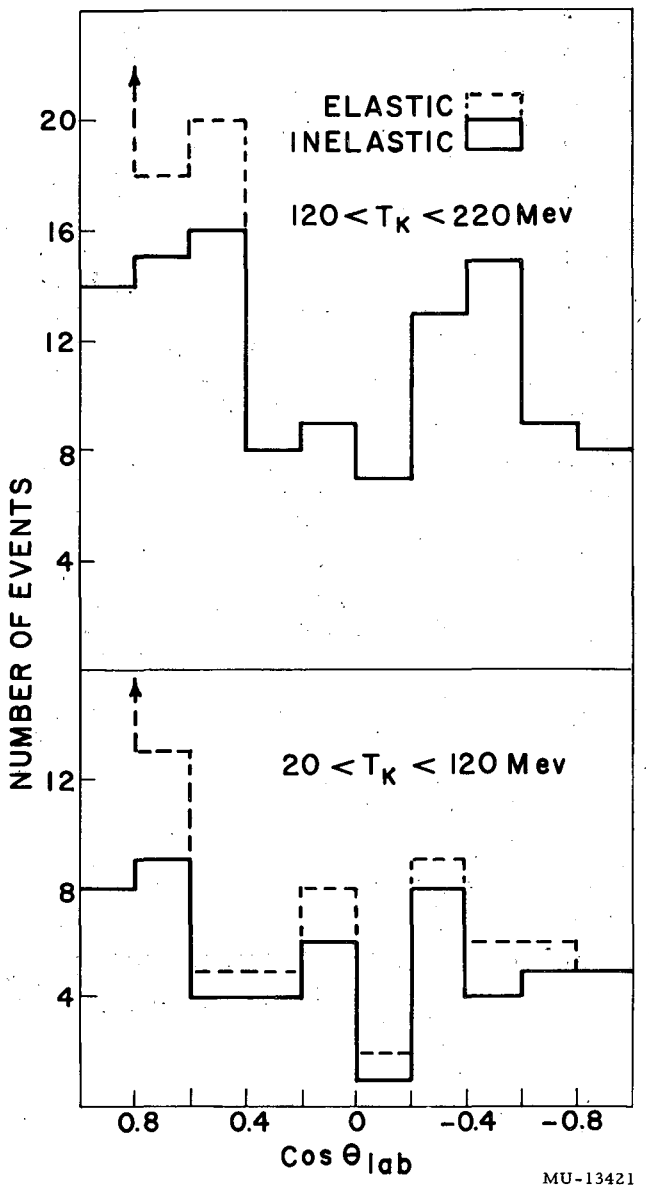

Fig. 8. Angular distribution of K^+ scatters in emulsion in two energy intervals 20 to 120 Mev and 120 to 220 Mev.

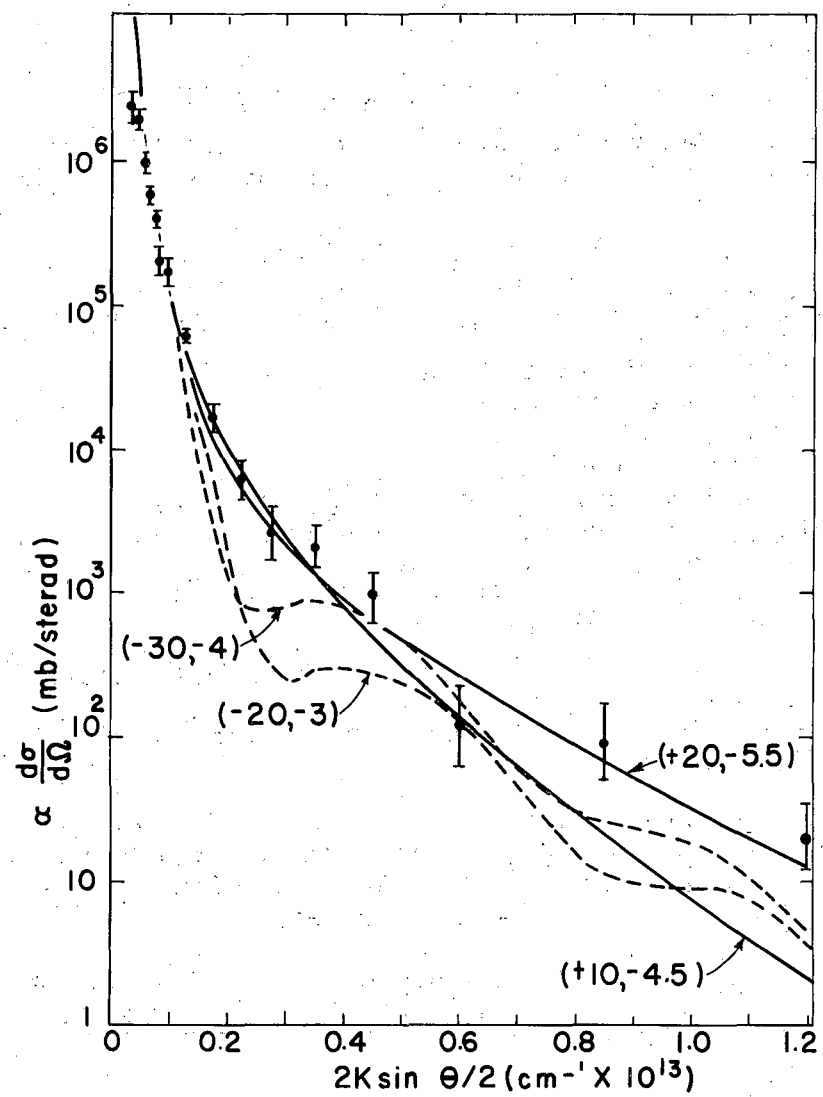

Fig. 9. Elastic differential cross section of K^+ mesons in nuclear emulsion in the energy interval 20 to 100 Mev. The theoretical curves are the result of a phase-shift analysis of our experimental data. Numbers in parentheses are the real and the imaginary potentials from which the curves were computed.

and Tiemann of Stanford University. The theoretical calculations in the lower-energy interval have been completed, and show that a repulsive real potential of +10 to +20 Mev and an imaginary potential of about -5 Mev fit the experimental data.

A STUDY OF NEGATIVE K MESONS

Francis M. Webb, Edwin L. Iloff, Frank Featherston, Warren W. Chupp, Gerson Goldhaber, and Sulamith Goldhaber

I. Interactions in Flight

We have followed 30.6 meters of K^- track and have found 102 K^- interactions in flight. Our results, summarized for $20 \leq T_K \leq 150$ Mev, are:

Number of absorption and charge-exchange stars	96
Number of inelastic scatters	4
Number of K-p scatters	1
Number of absorptions by hydrogen	1
Mean free path in emulsion (excluding hydrogen)	30.6 ± 3 cm
The corresponding average cross section	700 ± 70 mb

The corresponding nuclear radius R is

$$(1.31 \pm 0.07 \times 10^{-13}) \quad A^{1/3} \text{ cm.}$$

From isotopic spin considerations,

$$K^- \quad \frac{\text{charge-exchange scattering}}{\text{inelastic scattering}} \leq 2.$$

We thus have a limit on the charge-exchange cross section $\leq 8\%$ of the absorption cross section.

Because this work was carried out with a careful search for hydrogen scatters and absorption events, the small number of hydrogen events found by us must be attributed to a statistical fluctuation. A compilation of published results is given below.

Group	Energy interval (Mev)	Absorption in flight	Number of K^- + H scatters	Path length (meters)
This work	20 - 150	1	1	30
White et al	16 - 150	1	10	30
Barkas et al	30 - 90	2	6	49.5
		4	17	109.5

This gives a K^- + H scattering cross section = 48^{+15}_{-11} mb, a K^- absorption cross section of 11.4^{+9}_{-5} mb, and a total cross section of 60^{+15}_{-13} mb.

The mean life of the K^- meson, based on 20 decays in flight (including 3 events from Livermore and 6 events from Harvard-MIT, as published earlier in Phys. Rev. 102, 927 (1956)) is:

$$\tau_{K^-} = 1.3^{+0.38}_{-0.28} \; 10^{-8} \text{ sec.}$$

On 14.4 meters of K^- track in the energy region 80 to 160 Mev, we have measured all small-angle scatters down to 2° projected angle. The resulting differential cross section has been fitted with diffraction scattering off a black sphere of radius $1.31 \times 10^{13} A^{1/3}$ cm, which corresponds to the observed absorption cross section.

II. Interactions at Rest

The pion spectrum from K^- mesons at rest has been analyzed in terms of pions associated with Λ (π_Λ) and Σ hyperons (π_Σ) respectively. The analysis has been carried out with a Serber optical-model calculation. The following values of potentials have been used:

$$V_N = -42 \text{ Mev}$$

$$V_\pi = -40 \text{ Mev}$$

$$V_Y = -15 \text{ Mev}$$

$$V_K = 0 \text{ Mev}$$

A Gaussian momentum distribution of nucleons with a 1/e value of 20 Mev has been used.

From the analysis we found

$$\pi^-_\Lambda / \pi^\pm_\Sigma = 0.3 \pm 0.1 \simeq \Lambda^o / \Sigma^{\pm o} ,$$

which is the same as our estimate quoted at the sixth Rochester Conference, 1956. The error is statistical only. The present energy spectrum is based on the 1956 compilation (123 pions) and 46 additional pions our group has measured since. The results are shown in Fig. 10.

Thirty-seven Σ decays have been observed (26 from stars at rest, 11 from stars in flight). The angular distribution of the angle in the center-of-mass system between the decay-pion direction ($\pi^\pm$ or π^o, as the case may be) and the initial Σ direction is consistent with isotropy.

Ratio of $\Sigma^+ \rightarrow p + \pi^o$ decay mode to $\Sigma^+ \rightarrow \pi^+ + N$ mode

In emulsions there is a bias against the ($\pi^+ + N$) mode of about 10%. Also, only decays at rest can be identified reliably. The results reported by various groups are:

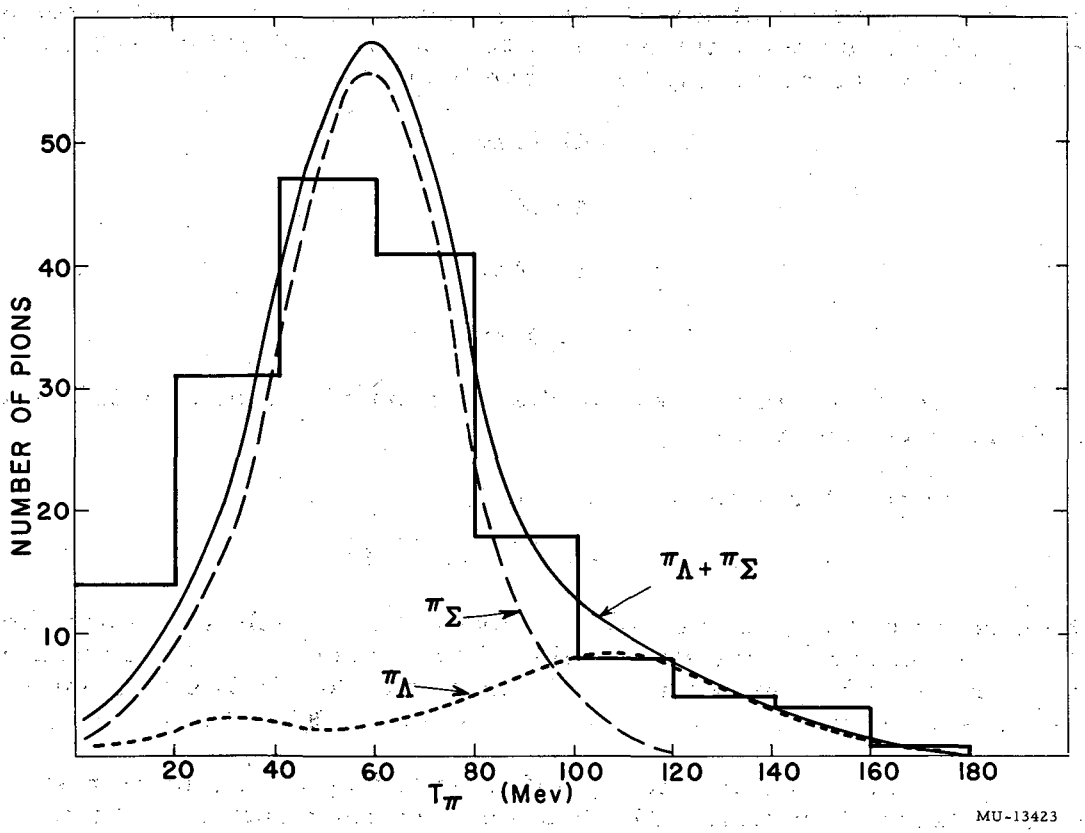

Fig. 10. Pion spectrum from K^- stars (169 pions).
$\pi^-_\Lambda / \pi^\pm_\Sigma \simeq \Lambda_0/\Sigma^{\pm 0} = 0.3 \pm 0.1$ (statistical error only).

Group	Mode of decay	
	$p + \pi^o$	$N + \pi^+$
This work	9	19
White et al.	4	8
Barkas et al.	13	13
Fry et al.	26	20
	52	60
Efficiency correction	52	~ 66
Alvarez et al.	27	31
	79	97

Ratio: $\Sigma_p/\Sigma_{\pi^+} = 79/97 = 0.81 \pm 0.12$

Table I

K^--hydrogen scatters

Group	Momentum (Mev/c)	Total amount of track studied (meters)	Number of $K^- + H$ Scatters	Number of $K^- + H$ absorptions
Emulsions				
This work	145–415	30	1	1
White et al.	125–415	30	10	1
Barkas et al.	170–310	49.5	6	2
Total		109.5	17	14.5
Hydrogen bubble chamber				
Alvarez et al.	10–170	26.8	4.5	14.5

Table II

K^--hydrogen cross sections derived from data in Table I

Momentum Mev/c	$\sigma_{Scattering}$ (mb)	$\sigma_{Absorption}$ (mb)	σ_{Total} (mb)
10–170	46^{+27}_{-18}	128^{+42}_{-32}	174^{+48}_{-38}
~ 170–415	48^{+15}_{-11}	11.4^{+9}_{-5}	60^{+15}_{-13}
900	---	---	52 ± 9

(Cork et al. ---Counters)

REPORTS ISSUED

Bruce Cork, Glen R. Lambertson, Oreste Piccioni, and William A. Wenzel, "Mean Life of K^- Mesons and Their Cross Section in Hydrogen," Phys. Rev. 106, 167 (1957).

Bruce Cork, Glen R. Lambertson, Oreste Piccioni, and William A. Wenzel, Cross Sections of Antiprotons in Hydrogen, Beryllium, Carbon, and Lead, UCRL-3650, Feb. 1957 (also to be published in Phys. Rev., July 1, 1957).

Bruce Cork, William A. Wenzel, Radiation Laboratory, University of California, and C. W. Causey, Jr., United States Naval Postgraduate School, Monterey, California, UCRL-3750, April 8, 1957 (also to be published in Phys. Rev.).

PHYSICS RESEARCH

Burton J. Moyer in charge

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

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

Nearly monoenergetic neutrons arising from the bombardment of tritium by deuterons accelerated by the 4-Mev Van de Graaff generator have been utilized to measure the energy resolution and background contamination of the 4-inch hydrogen bubble chamber neutron-spectroscopy experiment. Analysis of the resulting data indicates the presence of neutrons scattered from material surrounding the bubble chamber. A combination shield and collimator has been made in order to reduce the effects of this scattered neutron flux. The d-t reaction will be used to measure the effectiveness of this shielding at each angle for which the neutron spectrum is determined.

COSMIC-RAY NEUTRON EXPERIMENT

Wilmot N. Hess, H. Wade Patterson, and Roger W. Wallace

The B-36 airplane flight program has been finished with 12 flights--for a total of about 150 flying hours. Data have been successfully obtained at a range of altitudes from 10,000 ft to 40,000 ft with several different neutron detectors.

Data are now being taken on the ground at Albuquerque under varying thicknesses of lead absorber. A program is underway to calibrate the neutron detectors so that absolute neutron-counting efficiencies for different neutron energies will be known. When this is done the neutron energy spectrum in the atmosphere can be obtained from the previously measured counting rates.

π^0 MODES OF HEAVY-MESON AND HYPERON DECAY

John Osher and Sherwood Parker

With further experiment delayed pending Bevatron repair, this period was spent in making preparations for the last K-meson run in this series and in preparing the accumulated data for publication in the Physical Review.

From the data obtained in late January it was found that the ratio of the number of gamma counts from strange particle (θ^0) decay to the number of pion monitor counts was independent of target for the comparison of C, CH_2, and CD_2 targets. During the next run the statistical accuracy will be improved and a careful calibration will be made of the pion-monitoring telescope counts per incident proton for the various targets;

the refined calibration is necessary to determine the importance of intermediate pion states in associated production. The calibration procedure involves an exposure of a thin gold foil on the copper target, a simultaneous record of the pion-monitoring telescope counts, and finally the counting of the induced alpha activity in the foil from gold spallation to ytterbium. The alpha-counting arrangement has been refined to yield the necessary accuracy.

CLOUD CHAMBER STUDIES

Wilson M. Powell in charge

Experiments with Diffusion Chamber

5-Bev π^--p INTERACTIONS

William B. Fowler, George Maenchen, Wilson M. Powell, and Robert Wright

One hundred and thirty-seven interactions of 5-Bev negative pions in a hydrogen filled diffusion cloud chamber have been observed. Eighty percent of these collisions were inelastic. The total cross section is estimated to be 22.5 ± 2.4 mb. Analysis of the inelastic events shows that multiple rather than single pion production is the predominant process occurring at this energy. At least eight examples of quadruple pion production were observed. An average of 2.3 secondary pions was produced in the elastic events. This average multiplicity can be fitted by the Fermi statistical theory only by increasing the interaction radius occurring in the theory by 20%. The statistical theory, however, fails to account for the rather marked asymmetry found in the c.m. angular distributions of some of the particles emitted in inelastic events. Negative pions from low-multiplicity events are most frequently emitted in the forward direction in the c.m. system, and the angular distribution of nucleons from all events shows a strong backward peak.

This work is more fully described in the report,

George Maenchen, π^--Proton Interactions at 5 Bev (Thesis), UCRL-3730, April 1957.

Experiments with Propane Chamber

OBSERVATION OF θ_2^0

William B. Fowler, Richard Lander, and Wilson M. Powell

Analysis of previously obtained pictures is continuing. A summary of the latest results follows:

A propane bubble chamber in a 12-kilogauss magnetic field was exposed to a neutral beam designed to contain K^0 mesons but no particles above threshold for strange particle production and no $\overline{K}^0$. Of seventy-one Λ^0 type events, 24 had $Q(p, \pi)$ values consistent with 37 Mev. Two originated from stars in the propane. Λ^0 type background arises from $n + n \rightarrow p + n + \pi^-$ type events. Considering this background, at least 14 of the 71 events are thought to be Λ^0 decays from long-lived K^0 interactions. A check of 39 cases of $Q(p, \pi^-)$ from $n + p \rightarrow p + p + \pi^-$ type events shows no peak at 37 Mev. Of fifty θ-type events, 15 had $Q(\pi, \pi)$ values consistent with 214 Mev. Four originated in the propane. The remaining 35 are

probably θ_2^0 decays into $(\pi \mu \nu)$ or $(\pi e \nu)$, since θ-type background would involve double meson production, which is observed in this experiment to be extremely rare. These 35 cases include 3 electrons and 5 negative particles which are believed to be electrons.

Equipment and Techniques

30-INCH PROPANE BUBBLE CHAMBER

Wilson M. Powell and group

Final design for the inner chamber, expansion system, cameras, and illumination system was completed, and construction of these components was started during this quarter. The external pressure-vessel construction contract was let and delivery is scheduled for May 11. Work is in progress on the electronic and electrical control system, temperature control system, filling system, and reprojection system. Final assembly can probably be accomplished between June 1 and June 15.

PHYSICS RESEARCH

Emilio Segrè in charge

ANTIPROTON STUDIES

Work done by
Lewis E. Agnew, Jr., Owen Chamberlain, Tom Elioff, Donald Keller, Ronald Mermod, Ernest Rogers, Emilio Segrè, Herbert M. Steiner, Richard C. Weingart, Clyde Wiegand, and Tom Ypsilantis

Antiproton Collision Cross Sections

The apparatus used in these experiments has been described in the preceding Quarterly Report (UCRL-3689), and the nomenclature is the same as therein. The results that follow supersede the provisional numbers given in UCRL-3689.

The results obtained in the most recent antiproton run have been elaborated in order to obtain the relevant cross sections. Seven thousand feet of film have been scanned. Approximately 70,000 photographic images of oscilloscope sweeps have been measured and subsequently coded on IBM cards. The coding indicates the quality of the sweep, whether it corresponded to a scattering, to an annihilation, or to other processes.

Annihilations of antiprotons were detected by pulses in the Cerenkov counter Y, which detected only near-relativistic particles such as the mesons from an annihilation event. By making histograms of the numbers of pulses (in the Y counter) as a function of pulse height as read from the photographic film, we were able to construct bias curves. The bias curves could be extrapolated to zero bias, to correct in considerable measure for the presence of some very small annihilation (Counter Y) pulses. The efficiency of the annihilation counter has been estimated as 0.95.

As an example, in Fig. 11 we give a graph showing the pulse-size distribution with Y full of D_2O. As abscissa we have the pulse size and as ordinate the number of pulses. The dotted line shows the integral of the histogram (from the left) and the extrapolation to zero pulse size.

The results obtained, including statistical error only, are given in Table III for all elements except H and D. The cross sections indicated--as for example, $\sigma(>20^\circ)$--are the cross sections for elastic scattering to greater angles than 20° plus the annihilation cross section; σ_r indicates the total reaction cross section, mostly annihilation.

It should be noted that the number for $\sigma(>14^\circ)$ for Pb might be affected by multiple scattering. Even if this is so the annihilation cross section should be correct, but the total cross section reported is too high. For this reason we have put it in parentheses.

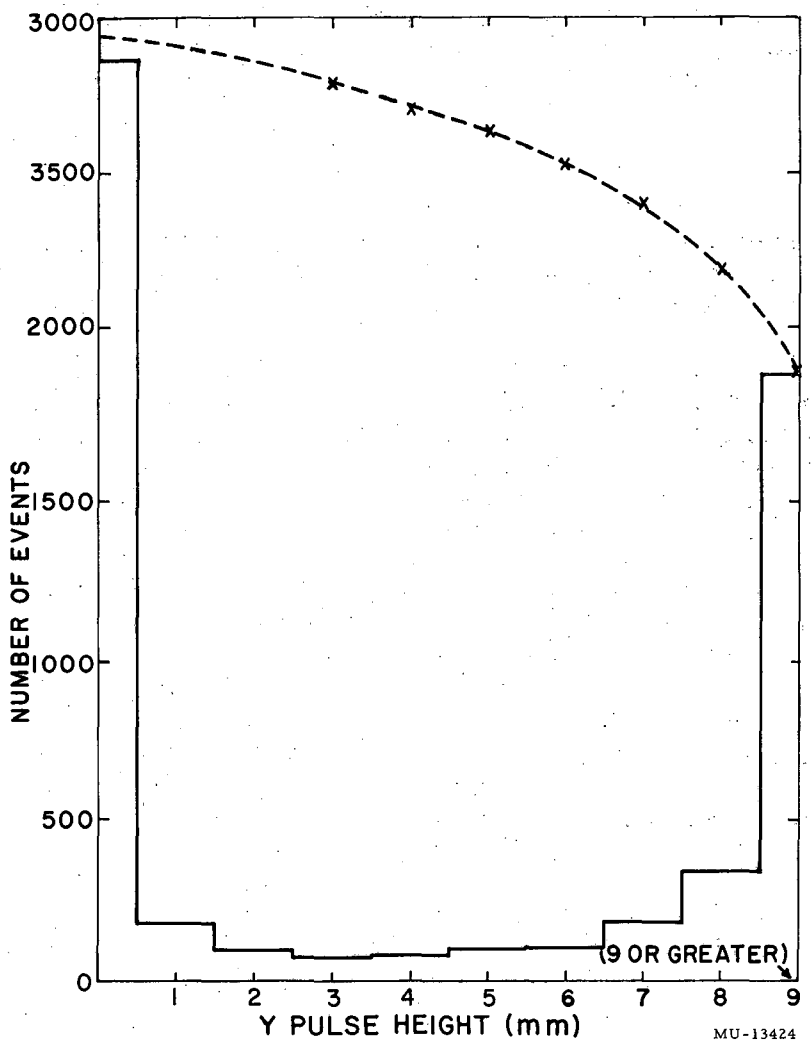

Fig. 11. Pulse height distribution for Y filled with D_2O. The dashed curve is the integral of the histogram from the left. The points for the small Y pulses are not included in this curve because they represent small pulses due to scintillations in the D_2O as well as annihilations. The extrapolation to zero Y pulse height is therefore made without including these points to obtain a more reliable estimate of the number of annihilations.

Table III

Antiproton interaction cross sections in complex nuclei
(in millibarns)

Element	$E_{\bar{p}}$ (Mev)	$\sigma(>20^{o})$		$\sigma(>14^{o})$		σ_r		σ (annih)	σ (annih) / σ_r
		p^-	p^+	p^-	p^+	$\bar{p}$	p^+		
O	457	519 ± 10	246 ± 2	559 ± 10	292 ± 1	599 ± 10	338 ± 3	456 ± 9	.76±.15
Cu	411	1220 ± 88	640 ± 4	1240 ± 82	719 ± 5	1260 ± 88	798 ± 8	1060 ± 61	.84±.30
Ag	431	1640 ± 183	924 ± 6	1630 ± 170	1052 ± 6	1635 ± 185	1180 ± 10	1500 ±157	.92±.43
Pb	436	2680 ± 254	1461 ± 10	(2910 ± 222)	(1720 ± 20)	(2680 ± 254)	(1461 ± 10)	2010 ±182	(.75±.32)

All errors are standard deviations due to counting statistics only.

The numbers reported are reasonably consistent with those we obtained last year.

For hydrogen and the neutron the case is more complicated, because a subtraction is necessary (H_2O minus O_2 or D_2O minus O_2). Moreover, if we want to infer the $\bar{p}$, n cross section from the $\bar{p}$, d cross section, we need to take into account the shielding done by one nucleon on the other in deuterium (Glauber correction). This correction is very large for the scattering of antiprotons on deuterons.

The results obtained are shown in Table IV.

Table IV

Antiproton-nucleon cross sections at 457 Mev
(in millibarns)

Target	$\sigma(\theta > 14^o)$		$\sigma(\theta > 20^o)$		Annihilation
	$\bar{p}$	p^+	$\bar{p}$	p^+	$\bar{p}$
proton	104± 8	25.1±1.2	102± 8	24.4±1.3	89 ± 7
"neutron"	70± 8	28.7±1.1	70± 8	21.1±1.1	46 ± 8
(neutron)^{corr}	104±12	29.2±1.1	104±12	22.5±1.1	68 ± 12

"neutron" = deuteron - proton

(neutron)^{corr} = corrected for shielding by proton in deuteron

$$\sigma^{corr}_{\bar{p}n} = \frac{1}{1-C\sigma_{\bar{p}p}} \text{"}\sigma_{\bar{p}n}\text{"} = 1.48 \text{"}\sigma_{\bar{p}n}\text{"}$$

$$\sigma^{corr}_{pn} = \frac{1}{1-C\sigma_{pp}} \text{"}\sigma_{pn}\text{"} = 1.02 \text{"}\sigma_{pn}\text{"}$$

Antineutrons

In another series of experiments we produced antineutrons by charge exchange and measured the charge-exchange cross sections of a few elements. The results are shown in Table V. The given cross sections refer to antineutrons produced into forward angles from 0° to 20° approximately.

Table V

Antiproton charge-exchange cross sections (in millibarns)

Target	$\bar{E}_{\bar{p}}$ (Mev)	Number of $\bar{n}$ observed	σ (per target molecule)
3 in. Pb	426	1	$3.7^{+4.1}_{-2.6}$
10 in. C	424	6	3.8 ± 1.5
10.5in. CH_2	455	15	11.5 ± 3

$$\sigma_H = \frac{1}{2}(\sigma_{CH_2} - \sigma_C) = 3.8 \pm 1.7$$

It will be noted that the antineutrons are best produced in hydrogen, and that the production in heavy elements (Pb) is strongly depressed. This is most probably because the antineutrons must be produced on the surface of the nucleus, as otherwise they are absorbed--as shown, for example, by analysis of the stars produced by antiprotons in emulsions.

Antiproton Production

Some qualitative data on the production of $\bar{p}$ were obtained by comparing the yield of $\bar{p}$ from a carbon target and from a CH_2 target in the same position in the Bevatron. The indications are that the production cross section in hydrogen, for the same energy in the center-of-mass system, is about eight times as large as the production on a proton contained in carbon, for the same c.m. energy. This is again a confirmation of the strong reabsorption of the antiprotons in the very nuclei in which they are produced.

The indications are that at the proton bombarding energy of 6.2 Bev the production of antiprotons by hydrogen in the target is surprisingly high. In terms of the cross section per nucleon, hydrogen in the target is about three times as effective as carbon in producing the antiprotons in the forward direction at an antiproton momentum of 1.2 Bev/c. As the result is rather startling, this experiment will be repeated as soon as practicable. If the present result is correct, it serves further to emphasize the strong reabsorption of antiprotons in complex nuclei.

ARC RESEARCH

Chester M. Van Atta in charge

HIGH-VACUUM AND ULTRA-LOW-TEMPERATURE REFRIGERATION

Hugh R. Smith

Construction work has continued on the conversion of the -130°F refrigeration systems for the cold baffles on the A-48 accelerator in Livermore. The first converted unit was put into operation during the last week of April. As predicted in the preceding quarterly report, a considerable improvement in the accelerator pumpdown time was evidenced even with only the one converted pump in operation.

Temperature measurements on the cold baffle indicated that the evaporator coil itself was running between -170°F and -185°F. The intermittent contact between the baffle vanes and the coil, plus the inherently poor conductivity of the stainless steel vanes, caused certain sections of the baffle to run considerably warmer. However, the noticeable benefits of the existing very cold areas indicate that the baffles will have sufficient pumping speed for the water vapor without mechanical modification.

Two more units are scheduled for completion during May and most of the parts of the remaining nine units have been completed.

The effort during the next quarter will be directed toward improving the basic binary refrigerant system. It is expected that system component simplifications can be introduced that will contribute toward attaining improved reliability and ease of maintenance.

ACCELERATOR OPERATION AND DEVELOPMENT

BEVATRON

Edward J. Lofgren in charge

A report for February, March, April 1957 is to be issued separately under the title "Bevatron Operation and Development. XIII."

184-INCH CYCLOTRON

Robert L. Thornton in charge

MODIFICATION

James T. Vale

During this period, two major problems had to be worked on. First, the hot-water control of the vibrating blades for the frequency modulation of the rf system had proved unsatisfactory in operation, and second, the beam from the cyclotron had to be extracted so that an external beam could be provided for experimental use.

The vibrating blades became a problem during the preliminary beam studies made in early January. It was found at that time that although the blades seemed to behave properly and could be controlled when they were being operated by themselves with no rf on the dee system, the situation was quite different when a beam was being accelerated. This is because of the sensitive behavior of the beam to various factors such as dee-voltage envelope, excitation of the cavity mode of the vacuum chamber, and, of course, the lowest rf frequency that the system reaches. These factors are all quite critically dependent on the phase of oscillation between the two sets of vibrating blades.

The hot-water system of control was inherently a very slow one, requiring hours to come to equilibrium, and therefore was incapable of handling fast changes. Two such effects are differential heating of the two sets of blades by the rf currents flowing over them, and the electrostatic forces at the tips of the blades due to the rf voltage across the gap. The first one, even though it is relatively slow, is far faster than the hot water can correct. The second one acts essentially instantaneously by changing the effective spring constant of the blade.

Both the above problems can be solved in theory if not in practice. The heating caused by the rf can be equalized by adjusting conditions so that currents of the same magnitude flow over the blades. The electrostatic forces can be balanced by operating both sets of blades with the same minimum gap. Assuming that these and other problems could be solved, there still remains the problem of maintenance. It takes a very long time to locate and correct trouble.

About this time it was noticed that the frequency of the vibrating blades depended, to some extent, upon the tightness of the face plate from which the vibrating blades are supported. The vibrating blades are not isolated in space, but are coupled to its supporting structure and through it to the face plate. Consequently, changes in these latter structures affect the blade frequency slightly.

Since the amount of frequency shift needed to provide control of the vibrating blades was small, about 0.2 cycle at their resonance of 64 cycles, it was thought that it might be possible to couple a small vibrating system to the blades and to control the resonant frequency of the blades by mechanically changing the small-system frequency. This was tried and shown to work, but no staisfactory method was devised to mechanically control the small system.

It was suggested by one of the operating crew members that the effective spring constant of the blades could be changed by using a direct current in the motors as well as the driving alternating current. The dc current would provide a magnetic force, pulling the blades together, that would be some function of their displacement and would thus constitute a compliance. By varying the dc, this compliance could be varied and thus the mechanical resonance of the blades could be changed.

This idea was tested and it appeared that enough frequency swing could be obtained to make the scheme practical. At the same time, magnetic pickups were installed close to the vibrating blades, whose output was some function of their amplitude of vibration. It then seemed possible to connect the signal from one of these magnetic pickups into an amplifier, the output of which was connected to the blade-driving motor. If sufficient gain and power were provided, the blades would then vibrate at their resonant frequency. This system would then eliminate the complicated one of the alternator generator, with its servo system for matching its frequency with that of the vibrating blades.

The present equipment now consists of two amplifiers, each capable of about 750 watts, two dc supplies of 100 amp each, and a control chassis which servos the amplitudes and phase between the two sets of blades.

The equipment has been debugged but has not had any extensive operation. The preliminary tests indicate that it should work satisfactorily.

The second problem, beam extraction, will be written up in detail later, so that just a brief survey will be included here. During the time of the preliminary beam studies and the vibrating-reed development, a group was busy on the computation of a regenerator for obtaining an external beam. At the beginning of April, a structure was built and installed in the cyclotron. Magnetic measurements were made, and they indicated that the field agreed with the calculated values. Consequently, the next step seemed to be to study the behavior of the beam through the regenerator.

The regenerator had been designed to accept beam from about the 82-inch radius, which corresponds to protons of about 720 Mev. It was determined earlier that essentially no beam was lost up to this radius, and that this seemed to be the optimum point for the regenerator. When the cyclotron was turned on with the regenerator in place, it was found that protons were coming out of the tank at about the desired position. Further studies were made on the regenerated beam to understand its behavior.

The protons coming out of the tank were focused vertically into a width of about 1 inch and were spread out horizontally over a distance of approximately 3 feet. Measurement of the beam over a 4-inch length gave 10^{-8} ampere. Therefore the total amount of beam possible to get into the steering magnet looked to be about 10^{-7} ampere. To do this would require a magnetic focusing channel between the regenerator and the tank wall. At the present time, this channel is under development.

60-INCH CYCLOTRON

W. B. Jones in charge

DEVELOPMENT

During the quarterly period (February, March, and April 1957), the over-all cyclotron operation was very satisfactory. The beam intensity has been high, with a peak intensity of 105 microamperes of alpha particles extracted. We are designing equipment to make full use of the high intensities available. At present, the beam current must be limited to prevent foil failures. We have a degaussing section, which can be attached to the target chamber to defocus the beam, but this is cumbersome to handle and time-consuming to install. Additionally, the beam intensity is reduced by a factor of two when this equipment is used. The internal beam is in excess of one milliampere on an area of 1 cm^2, so that special techniques will be necessary to fully use it.

OPERATION

Summary of operations as prepared by Peter McWalters for this quarter:

Alpha bombardments	581.0 hr
Proton bombardments	158.7 hr
Deuteron bombardments	199.7 hr
Experimental bombardments	88.6 hr
Operational total	1,028.0 hr
Outage time	160.5 hr
Available time	1,188.5 hr
Shutdown	903.5 hr
In Memoriam (Dr. Hamilton)	12.0 hr
Holiday	32.0 hr
	2,136.0 hr

An operating efficiency of 86.4% was maintained throughout this quarterly period.

LINEAR ACCELERATOR

James Donald Gow in charge

OPERATION

The 32-Mev proton linear accelerator operated routinely throughout this quarter. The major share of bombardment time was on the p-n energy-distribution experiment for Moyer's group, and on high-energy β-ray spectra with a spiral-orbit spectrometer. Runs also were made for Welch on the β-ray spectra of Wigner-series radioelements with the 180° β-ray spectrometer. Some operation for the production of various radioelements continued.

HEAVY-ION LINEAR ACCELERATOR

Chester M. VanAtta in charge

CONSTRUCTION AND DEVELOPMENT

Edward L. Hubbard

In order to increase rate of rise of the rf voltage in the cavities at the beginning of the pulse, the A2332 oscillators were converted to amplifiers, and the output power of the driver amplifier was increased. With these changes it became possible to build up the rf in the cavities at a repetition rate of 2 pulses/sec without trouble from ion lock.

On April 11 the first full-energy beam of 140-Mev nitrogen ions was accelerated by the machine. The average beam current was 8×10^{-9} meter amp. Experience in operating the machine since then has increased the beam current to 4×10^{-8} meter amp. Most of the beam is focused in a spot about 1/8 by 3/8 in. at a point 1 ft from the end of the machine. Carbon ions have also been accelerated. Beam currents and focusing are about the same as those for nitrogen ions.

Although most of the time has been spent debugging the accelerator, several bombardments have been made for the group of chemists who are looking for new heavy elements.

SYNCHROTRON

Edwin M. McMillan in charge

RESEARCH PROGRAM

Robert W. Kenney

During the period February, March, April the synchrotron ran extremely well.

Robert Cence has continued the development of the monochromatic photon beam apparatus, with encouraging results. If the device can be made to select a sufficiently large flux of photons of a given energy from the synchrotron beam, those selected photons will be employed to investigate internal momenta of nucleons in the nucleus by observing photoprotons ejected from nuclei.

Burns McDonald has begun to look at photodeuterons from light nuclei in order to study some aspects of nuclear structure. No data are yet available.

Robert Kenney, Edward Knapp, and Victor Perez-Mendez have completed the forward-angle observations of the reaction $\gamma + p \rightarrow \pi^+ + n$. The data from 0° to 53^o(c.m.) show the predicted dip near 20° in the differential cross section, and essentially confirm the expected interaction of photons with the virtual meson cloud around the nucleon. A letter has been submitted to the Physical Review.

Robert Kenney, Edward Knapp, and Victor Perez-Mendez have begun to measure the ratio of photopions from the two reactions $\gamma + D \rightarrow \pi^+ + 2n$ and $\gamma + p \rightarrow \pi^+ + n$ at several angles and energies, in an effort to determine the probability of nucleon spin flip in the photomeson-production process under various conditions. This work is currently under way, and no final data are yet available.

Scanning of the 4-inch bubble chamber film is continuing to provide additional data on the wide-angle electron-pair production. Some effort is being applied to the theoretical aspects of this problem as well as to the problem of electron-triplet production.

OPERATION

Priestly T. Hibdon

During this period the synchrotron was run entirely for physics research experiments. The beam was fairly stable, with peak intensities of 5×10^8 electrons per pulse, except when running for Robert Cence's experiment, which required low beam intensities.

The contractor is working on the radiation shield vault for linac No. 2, and the vault should be completed about the first of July. The design for the mezzanine in Building 68 has been completed by Plant Engineering and the contract is out for bids. Work on the mezzanine is expected to start in May.

The 2-megawatt klystron has been installed in the 3-Mev injector linac, and measurements on the beam are being made to determine the size, the energy spread, and the angular divergence of the beam.

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