trograph, from the coincidences observed between the 600-kev beta-spectrum and conversion electrons of the 320-kev gamma-ray, and from the absence of gamma-gamma coincidences. A search for long-life metastable states has yielded negative information. A ground to ground beta-transition has not been observed experimentally in the present measurements. On the basis of relative intensities, the *ft* value for the 825-kev beta-transition is $\sim 3\times 10^7$, for the 600-kev transition $\sim 4\times 10^7$, and for the 380-kev transitions $\sim 5\times 10^6$.

Of the three gamma-rays, most information is available on the 91-kev transition. Although it appears to be highly converted, and has a K/L-ratio of about 2.5,* the mean life is expected to be less than 5×10^{-7} second, since coincidences are observed. In the case of the 320-kev and the 534-kev gamma-rays, K-conversion lines are considerably more intense than L-conversion lines.

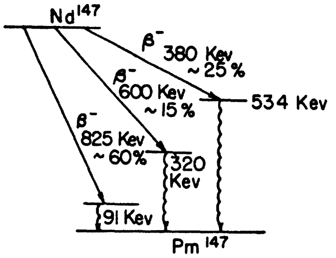

FIG. 7. Partial decay of Nd^{147}.

The authors wish to thank Mr. C. McWhirt and the crew of the machine shop for the construction of equipment, and Messrs. E. B. Dale and P. Zeldes for assistance in taking readings. We also wish to express our gratitude to the Ohio State University Development Fund for grants to carry on this research.

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* Self-absorption in the source may account for the low experimental value of this ratio.

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The Proton Component of the Cosmic Radiation at Sea Level*

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The range spectra of mesons and protons in the sea-level cosmic radiation have been investigated with a cloud chamber that had within its volume a total of 10 cm, of lead equivalent absorbing material. Measurements were made with absorbers equivalent to 2, 7, 17, and 48 cm of lead above the apparatus. The masses of stopping particles were determined by observing the momentum and range of each particle. One hundred and sixty-one mesons (mass$=205\pm 2m_e$) and 72 protons (mass$=1900\pm 44m_e$) were observed. No evidence was found for the existence of any particles with intermediate mass. Data obtained under each of the four thicknesses of moderating absorber were used to give four points on the differential range spectra for mesons and protons. The meson spectrum has a peak occurring in the range between 17 cm and 30 cm of lead. The observed proton component can be interpreted either as the residual of a flux of protons which is incident on top of the moderator and degraded in energy with passage through the moderator, or as a flux of protons produced in the moderator by an incident neutral radiation, probably neutrons. The proton range spectrum fits an exponential absorption law with a mean free path of 12 cm of lead. This is just the order of attenuation to be expected from nuclear interactions of protons or neutrons. Thus, if the protons are incident on the moderator, their differential range spectrum would have to have been flat in the region between 8 and 54 cm range in lead. This implication, together with the behavior of the proton component in the lead absorber plates observed in the cloud chamber, points to the incident neutron hypothesis as the more probable explanation of the observed protons.

I. INTRODUCTION

IN the experiment of Merkle, Goldwasser, and Brode[1] it was found that the penetrating component of the cosmic radiation with ranges between 4 and 13 cm of lead consisted of approximately equal numbers of mesons and protons. The observed flux of stopping protons amounted to about 1 percent of the total penetrating component. The experimental observations reported in this paper were undertaken to determine the nature of the proton component and its source.

The apparatus used was the same as that used in the previous experiment with a few minor modifications. A schematic diagram is shown in Fig. 1. The momentum of a particle was measured by observation of the radius of curvature of its trajectory in a magnetic field of 4500 gauss. Particles traversing the momentum cloud chamber with residual ranges of less than 11 cm of lead were observed to stop in one of a series of copper and lead absorber plates mounted in the second cloud chamber. Numerical integrations of the energy loss equation for copper and for lead were then used in order to calculate masses from the observed momenta and ranges. Recent direct observations of range and velocity of high energy protons made in the 184-in.

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* Assisted by the joint program of the ONR and the AEC.

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[1] Merkle, Goldwasser, and Brode, Phys. Rev. 79, 926 (1950).

cyclotron have been used to determine the mass values.[2,3]

The previous measurements under the equivalent of 2 cm of lead were extended by the use of additional moderating absorbers to permit observations under 7, 17, and 48 cm of lead. This absorbing material was located above the three-tube Geiger counter telescope which was used to trigger the apparatus.

The limiting factor in accurate mass determination was again found to be the turbulence in the momentum cloud chamber. A study of the no-field tracks revealed a mean residual curvature of +0.016 reciprocal meters, with a probable error of ±0.016 reciprocal meters. Each momentum calculation was corrected for the observed mean no-field curvature.

II. MASS DATA

In this experiment 8500 events were photographed of which 1400 were without a magnetic field. The mean values for the data obtained here, together with that previously reported,[1] involve 161 stopping mesons and 72 stopping protons. For the mesons the mean mass is found to be $m=205\pm 2\, m_e$. For the protons $m=1900 \pm 44\, m_e$. The mean value of the meson masses measured under 7, 17, and 48 cm of lead is $208\pm 2\, m_e$. This is significantly higher than that obtained in the previous experiment with the same apparatus, but with no lead above it. The mean mass values for the 64 positive mesons and 49 negative mesons under 7, 17, and 48 cm of lead agree within the probable errors assigned. The observed mass shift cannot, therefore, be explained by a consistent change of the mean turbulent curvature. A change in the calibration of the magnetic field would account for the shifts, but the field was checked with a flux meter, which in turn was calibrated by the use of the proton resonance. The comparison of the mean masses from the different groups of measurements seems to indicate that there is present some unknown source of systematic fluctuations which makes the values of the probable errors relatively meaningless. It is possible that a small contamination of pi-mesons and deuterons is present and is dependent on the amount of absorber placed over the apparatus.

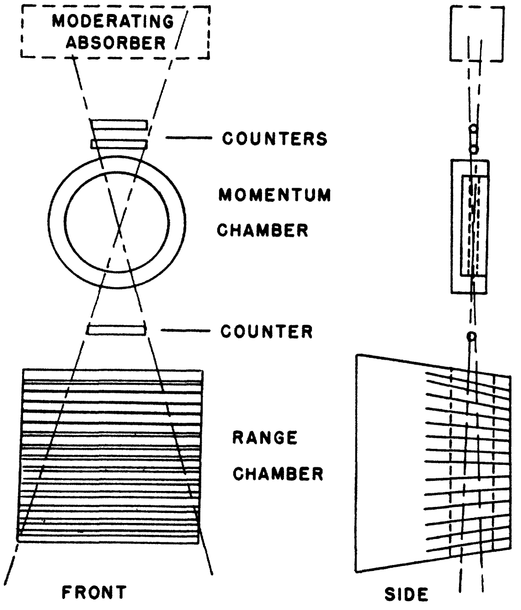

FIG. 1. Schematic diagram of apparatus.

III. RANGE DATA

Table I shows the significant data obtained under 7, 17, and 48 cm of lead moderator and under 2 cm of lead equivalent during the previous work.

Using these data, differential range spectra for mesons and protons are presented in Fig. 2.

IV. MESON COMPONENT

The meson spectrum shows the expected peaked shape, but the peak is much more pronounced than that which has been found by most other workers.[4,5] It should be noted that counter experiments and cloud chamber work which do not specifically identify the particles whose ranges are observed, may lump the proton stopping rate with that of the mesons. Doing this with the data of the current experiment gives a spectrum which is relatively flat in the low range region and then drops off at ranges greater than 25 cm of lead. There is one remaining important discrepancy between this explanation and existing experimental results. This lies in the results of counter experiments by Sands[6] which tag the stopping mesons by observation of the delayed coincidences of the decay electrons. The spectrum obtained in this way was also much less peaked than that shown for mesons in Fig. 2. This may be due in part to an inaccuracy of the operating time under 2 cm of lead equivalent in the first part of this experiment. During that part of the experiment the dead time of the apparatus fluctuated considerably, but the time given is believed to be within 10 percent of the correct value.

V. PROTON COMPONENT

In order to calculate the flux of protons in various prospective range intervals, as they are present in the atmosphere above the moderating absorber, it is necessary to correct the observed flux of stopping particles by a factor consistent with the rate of removal of protons through nuclear interaction processes in the moderating absorber. Although no exact value for this cross section is known, most of the available data points to the geometrical cross section of the nucleus as a

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[2] C. J. Bakker and E. Segrè, Phys. Rev. **81**, 489 (1951).

[3] E. Segrè and R. L. Mather, private communication.

[4] For a summary, see B. Rossi, Revs. Modern Phys. **20**, 537 (1948).

[5] L. S. Germain, Phys. Rev. **80**, 616 (1950).

[6] M. Sands, Phys. Rev. **77**, 180 (1950).

TABLE I. Observed range data.

Mean Pb equiv. traversed (cm)	Hours operating time	No. of stopped mesons	No. of stopped protons	Stopping mesons per hr	Stopping protons per hr	Mean meson mass	Mean proton mass
8	518	48	53	0.09	0.102	194	1875
13	220	43	14	0.20	0.064	214	1989
23	142	35	4	0.26	0.028	207	1799
54	230	35	1	0.15	0.004	201	2625

reasonable approximation throughout the energy region under investigation. Thus if the protons were incident on the moderator in some arbitrary energy spectrum, from consideration of ionization losses only, there would exist a prospective differential range spectrum for the protons in the air above the moderator, and this can be represented as:

$$(dN/dR)_0=f(R). \tag{1}$$

To investigate this spectrum, the stopping rate under several thicknesses, R_i, of absorber must be observed. But in R_i centimeters of absorber, nuclear interactions occur to the extent that the observed stopping rate would be:

$$(dN/dR_i)_{R_i}=f(R_i)\exp(-R_i/L_{\mathrm{Pb}}), \tag{2}$$

where L_{Pb} is the mean free path of the protons for nuclear interaction, $L=1/n\sigma$ where n = number of nuclei per cc of absorber and σ is the cross section per nucleus.

The proton spectrum of Fig. 2 is replotted on semilogarithmic coordinates in curve 1 of Fig. 3. The experimental points are found to be consistent with an exponential attenuation, $e^{-R/L}$. The slope of the straight line shown gives $L\simeq 12$ cm of lead. But, using the geometric cross section of the lead nucleus, $\sigma=\pi(1.5)\times10^{-26}\times A^{\frac{1}{3}}=2.47\times10^{-24}$ cm^2, gives $L_{\mathrm{Pb}}=12$ cm. This means that in Eq. (3), $f(R)$ must be a constant, and thus Eq. (1) now becomes

$$(dN/dR)_0=\text{constant}$$

in the region investigated. In other words, if the stopping protons observed are, indeed, a part of a proton flux incident above the moderator, then this differential spectrum $(dN/dR)_0$, is constant between 8 and 54 cm of lead. From this assumption, one would be forced to the conclusion that protons constitute an appreciable portion of the sea-level radiation. In the first part of the experiment, with 8 cm average range, it was found that the numbers of stopping mesons and protons were roughly equal. The question of possible selectivity of the apparatus has been investigated. The magnetic field across the momentum cloud chamber constitutes a momentum selector which can prevent low momentum particles from entering the range chamber. Calculations of this effect have been carried out, and they show that the effective solid angle of the apparatus for the detection of mesons is about two-thirds of that for the detection of protons. The assumption that the flux of protons at sea level with prospective ranges between 8 and 54 cm is constant leads to the improbable conclusion that 25 percent of the penetrating particles in this range interval are protons.

There is another possible interpretation of the observed proton component. If it is assumed that at sea level there is a neutron component with energies in the neighborhood of 200 Mev, then these neutrons may be expected to interact with the nuclei of any absorbing medium. Some of these interactions will have the nature of stars of several prongs. Others will have the nature of knock-on or charge exchange processes. Protons originating from such interactions will have all energies up to that of the incident neutrons. Since the cross section for neutrons is about equal to that for protons, the attenuation which is observed under increasing thicknesses of moderator is just what would be expected due to the attenuation of the neutron flux in the moderator. The protons observed to stop are then mainly produced either in the absorber or in the atmosphere within one mean free path of the top counters. The minimum neutron flux required at sea level would be about 1 percent of the total hard component, but the requirement is strongly dependent on the relative frequencies of various kinds of interactions.

If the protons observed in this experiment are the penetrating portion of an incident flux of protons, then the attenuation of protons observed within the range chamber in all parts of the experiment should merely be a continuous part of the attenuation observed when operating under various thicknesses of absorber. To test this, the range chamber was divided for the purpose

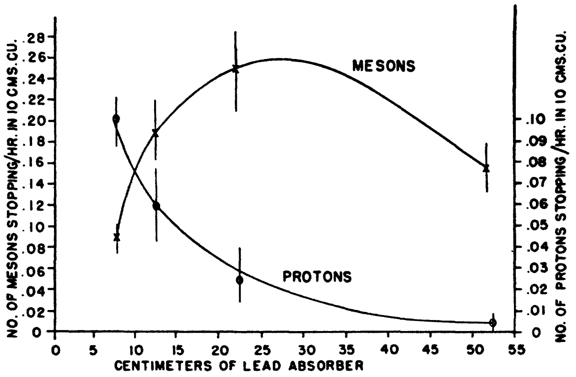

FIG. 2. Differential range spectra for mesons and protons obtained by adding moderating absorber above apparatus.

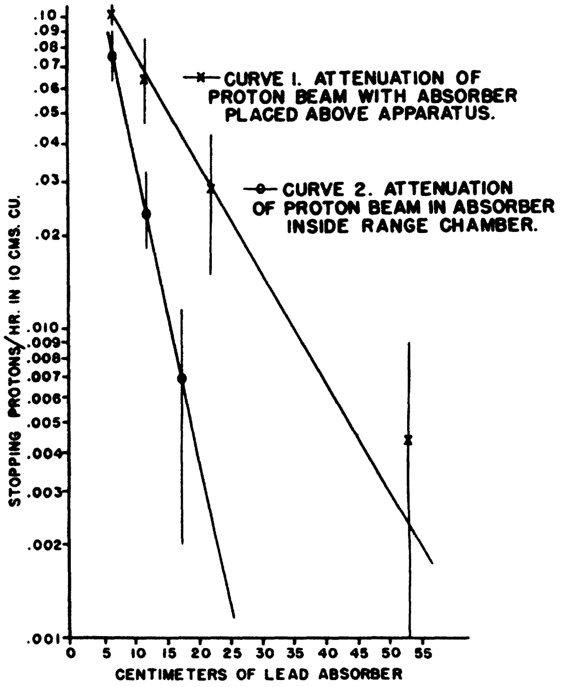

FIG. 3. Semi-logarithmic plot of differential range spectra for protons: 1. with moderating absorber added above apparatus; 2. with increasing absorber inside range chamber.

of statistics into two 4.5 cm range intervals. The flux of protons stopping in the top 4.5 cm and the flux stopping in the bottom 4.5 cm, when operating under 2 cm and 7 cm effective lead moderator, are plotted as curve 2 in Fig. 3. The flux under 7 cm moderator has been normalized to that under 2 cm so as to make the common points at 11.5 cm coincide. The results can be interpreted as a true proton attenuation only if there is no important instrumental attenuation from the top to the bottom of the range chamber. The observed meson stops occurred with essentially equal probabilities in the top and bottom of the chamber. Thus it can be safely assumed that there is no significant instrumental attenuation.

The slope of this new curve gives $L \simeq 4$ cm. The difference between the slopes of these two lines is believed to be significant. The results thus appear to be inconsistent with the incident proton hypothesis.

According to the incident neutron hypothesis, the curve for an absorber placed above the counters shows essentially the attenuation of the primary neutrons; while the attenuation observed within the range chamber merely represents the range spectrum of the secondary protons. This depends on the spectrum of neutrons and on the probabilities of various types of interaction. The fact that curve 2 in Fig. 3 is steeper than curve 1, means simply that short range secondaries are more probable than long range ones.

The observations reported in this paper appear to support the hypothesis that most of the protons observed coming from the atmosphere and from lead absorbers up to 54 cm in thickness are secondary particles from neutron reactions. The proton flux observed in this work is in excess of that observed by other workers both in this laboratory and elsewhere. Experiments are now being undertaken to resolve this discrepancy and to check the neutron reaction hypothesis.

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