The Absorption Curve of the Cosmic Radiation in the Stratosphere*

MARCEL SCHEIN AND VICTOR H. YNGVE
Department of Physics, University of Chicago, Chicago, Illinois
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The absorption in lead of cosmic-ray particles has been measured at an altitude of 5.7 cm Hg with hitherto unattained accuracy. The absorption at this altitude is compared with the absorption at sea level. It is found that the soft component shows an increase by about a factor of 90. The hard component shows an absorption length of about 220 grams per cm² of Pb, very different from the sea level absorption of μ-mesons. It is concluded that most of the penetrating particles at 5.7 cm Hg are nucleons.

BALLOON flights have been made to measure the absorption in lead and in air of the cosmic radiation. Absorption in lead was measured by a technique which gives the penetration through a number of thicknesses simultaneously with one apparatus on one flight. This technique has a number of advantages over the other one of sending up many flights each with a simple telescope. In the first place, errors in measurement of the pressure cannot affect the shape of the absorption curve in lead at any one altitude. Secondly, time variations and atmospheric temperature effects can have no effect on the absorption curve in lead at any one altitude. Finally, internal checks are possible on the proper operation of the apparatus by observing the number of counts recorded simultaneously in the different telescopes.

The geometry is shown in Fig. 1. Altogether 17 counters were used in eight fourfold coincidences. Six of these coincidences form telescopes giving the counting rate through lead thicknesses of 0, 2, 4, 8, 12, and 18 cm. All of these telescopes subtend the same solid angle for single particles passing through along straight lines.[1] Five of the six have the solid angle defined by the two extreme counters, which are 28 cm apart. However, in the case of the telescope with 18-cm Pb, the counters definining the solid angle for straight line particles are not the extreme counters, because it was not possible to put this much lead between counters H and M. In order to make an 18-cm telescope, the three counters G, in parallel, were placed above the lead and they more than cover the solid angle. The solid angle of this telescope thus becomes larger than the others for particles which interact in the lead to produce secondaries which can trip the lower counters. Corrections can be made for this effect because the 18-cm telescope shares part of its solid angle with other telescopes with lesser amounts of lead. These corrections were obtained by counting the events in which a count was registered simultaneously in the 18-cm telescope and in various other telescopes.

The circuits which were developed in this laboratory use cathode follower input circuits followed by germanium diode coincidence circuits, multivibrators, and a photographic recorder using neon bulbs. The telescopes $ABCF$ and $BCDH$ also included a scale of two with two neon bulbs which flashed alternately. The resolving time of the coincidence circuits was 20 μsec, and hence, accidentals were negligible. The diode coincidence circuits make possible a considerable saving in

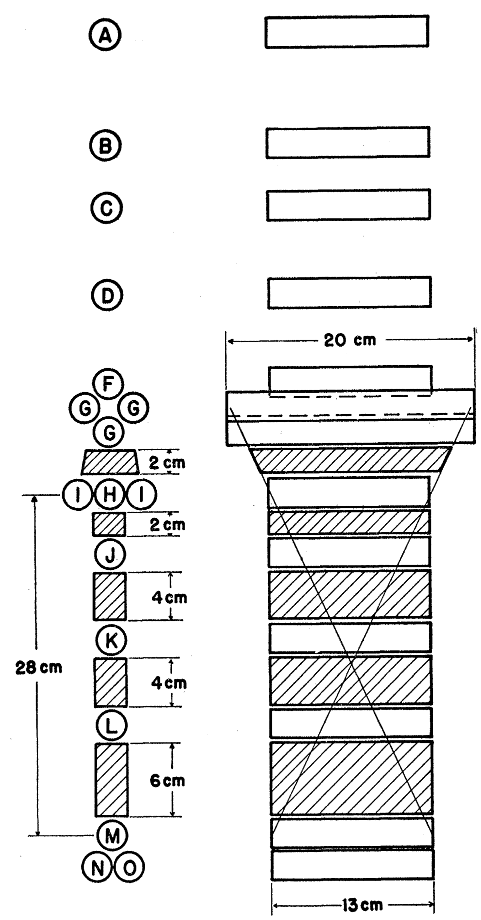

FIG. 1. The counter geometry. The counters are one inch in diameter. The active lengths shown are the lengths of the center wires. Coincidences are:

Cm Pb	0	2	4	8	12	18		
Counters	*ABCF*	*BCDH*	*CDFJ*	*DFJK*	*FJKL*	*GHLM*	*BDHI*	*HMNO*

* Assisted by the joint program of ONR and AEC. The data contained in this paper was presented by one of the authors (Marcel Schein) at the Cosmic-Ray Conference in Pasadena in 1948.

[1] The other two registered multiple events below 2 and 18 cm of lead and had counting rates of 4.2 and 1.9 counts per minute, respectively.

vacuum tubes. In this apparatus the saving amounted to 10 tubes.

The apparatus was launched from Chicago and was carried by a cluster of 20 rubber J2000 balloons to the stratosphere. After reaching a maximum altitude, the balloons leveled off at a pressure of 5.7 cm Hg for $6\frac{1}{2}$ hours while each telescope gave several thousand counts. The total length of the flight was 10 hours. It landed in the hills of West Virginia, about 450 miles from Chicago.

Corrections for the dead time of the counters and for the dead time of the recorder have been applied to the actual counting rate. The corrected counting rate at 5.7 cm Hg is shown in Table I, and gives the absorption of the cosmic radiation at this altitude. The indicated errors represent the total uncertainty of each point.

TABLE I. Counting rate at an altitude of 5.7 cm Hg through various thicknesses of lead absorber.

Cm Pb	0	2	4	8	12	18
Counts per minute	19.96	15.22	11.20	8.42	6.78	4.93
Total uncertainty	±0.23	±0.20	+0.26 −0.22	+0.21 −0.19	+0.18 −0.15	±0.35

It is instructive to compare the absorption at this altitude with that at sea level. Rather good sea level counting rate data was obtained during pre-flight tests. However, since most of the tests were made indoors, they do not give a true indication of the absorption in the smaller thicknesses of lead. So, for purposes of comparison, the sea level curve obtained outdoors by Nielsen and Morgan[2] is shown in the lower curve in Fig. 2. The curve of Nielsen and Morgan is represented by the line and is made to fit accurately our sea level points at the larger thicknesses of lead.

A comparison of the two curves shows very clearly the difference in the composition of the cosmic radiation between sea level and an altitude of 5.7 cm Hg, which is close to the altitude at which the soft component exhibits a maximum at 52° north geomagnetic latitude. Both curves show a steep absorption in the first few cm of lead characteristic of the electronic component. If one extrapolates the curve of greater lead thickness to zero and measures the area between the extrapolated curve and the measured one for small thicknesses of lead, one gets a rough measure of the soft component. From this one finds that the soft component increases by about a factor of 90 between sea level and an altitude of 5.7 cm Hg.

[2] W. M. Nielsen and K. Z. Morgan, Phys. Rev. **54**, 245 (1938).

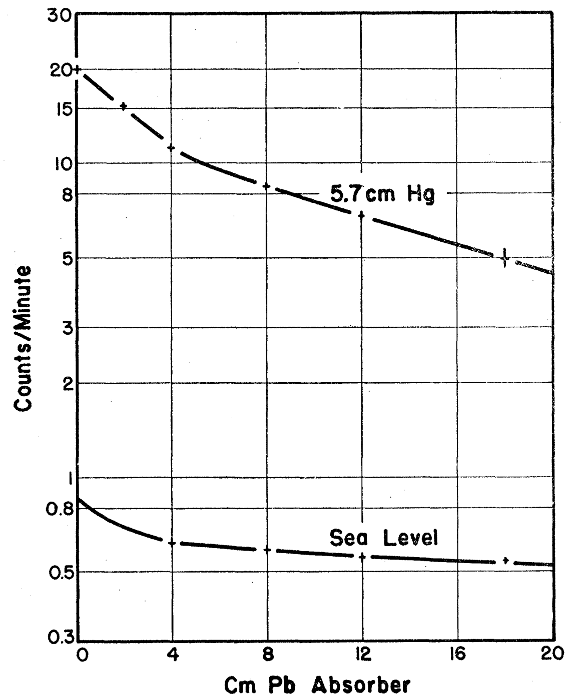

FIG. 2. The upper curve gives the counting rate through several thicknesses of lead obtained at an altitude corresponding to 5.7 cm Hg pressure. The lower curve gives the sea level data of Nielsen and Morgan normalized to our sea level data, which is shown by the points.

With larger thicknesses of lead, the absorption curve at 5.7 cm Hg shows a further significant drop with lead thickness, which is practically missing from the sea level curve. At sea level the remarkable flatness of the curve is known to be due to the fact that the particles penetrating more than a few cm Pb predominantly consist of μ-mesons.[3] In contrast to this flatness at sea level, it is interesting to note that the absorption curve for more than a few cm Pb at an altitude corresponding to 5.7 cm Hg pressure is nearly exponential with an absorption mean free path of about 220 grams per cm^2 similar to that of high energy nucleons.[4]

It is then concluded that most of the particles of the penetrating type consist of nucleons rather than μ-mesons at high elevations. This conclusion is further supported by the fact that the comparison of the absorption in lead and in air does not show an anomalous absorption in air between 4 cm Pb and 12 cm Pb. Due to the low density of the air at this high elevation, a very considerable anomalous absorption would be expected if the particles discharging the telescope were μ-mesons.

[3] M. G. Mylroi and J. G. Wilson, Proc. Phys. Soc. (London) **A64**, 404 (1951).
[4] T. G. Stinchcomb, Phys. Rev. **83**, 422 (1951).