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Absorption Curve and Production of Slow Cosmic-Ray Protons at Low Altitude

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WITH the apparatus described in the preceding letter,[1] the production of single, non-cascade-producing particles by a non-ionizing radiation was investigated. Also, statistics were made of pictures showing ordinary mesotrons and protons stopped by 20-cm lead.

The events represented by the absorption curves in Fig. 1 are those where a particle never showed multiplication upon traversing one cm of lead and successive absorbers. The curves are average curves evaluated from measurements taken on different days with different absorbing materials. A constant factor close to unity was applied to some of the original curves in order to account for changes in intensity due to meteorological conditions.

The upper curve gives the total hourly rate of cosmic rays at Climax, Colorado, (11,500 feet), on a mass scale, with the exclusion of what is generally termed the "soft component" with its multiplicative character. The slope of this curve indicates the well-known presence at this altitude of low energy particles which must have been produced close to the apparatus in the atmosphere. The production of mesotrons by non-ionizing rays as previously reported[2] must be partly responsible for the presence of these particles.

With the apparatus here used a production process was observed which seems to account well for the particles responsible for the steep drop of the absorption curve below 5-cm lead. In the top layer of 1-cm lead and *not* at larger absorber thicknesses, single, non-multiplying particles are produced by non-ionizing rays. The lower curve of Fig. 1 gives the absorption curve of these particles measured after they emerge from the layer of lead in which they are produced. The data for the thickness of absorber include 1-cm lead for the producing layer.

Particles with the short range observed here were de-

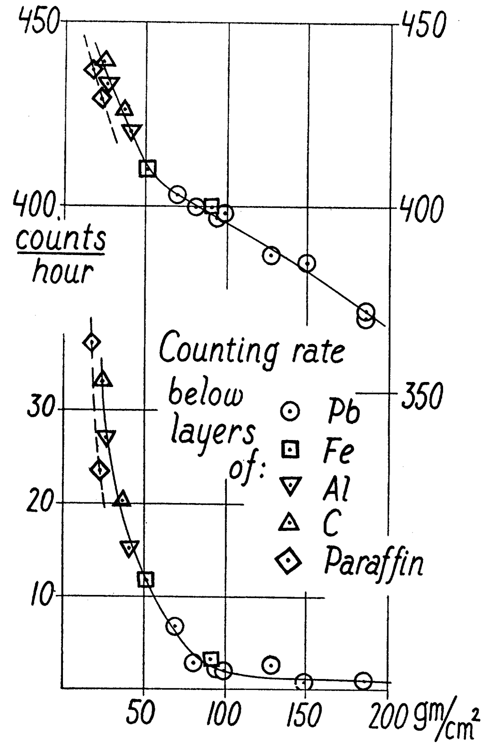

FIG. 1. Above: An absorption curve of non-multiplying cosmic rays at Climax (11,500 feet). Below: An absorption curve of slow protons produced by non-ionizing rays in 1-cm lead at Climax. The experimental error is to be inferred from the scattering of the values about the curves

tected on Mt. Evans by Powell[3] who identified them in a cloud chamber as protons. There can be little doubt that our particles are identical with the ones observed by Powell and are therefore protons. Nielsen and Powell[4] recently reported the absence of slow mesotrons on Mt. Evans. Paraffin, with its content of free protons, should absorb our protons stronger than mass-proportional. Indeed, the intensities measured below paraffin (Fig. 1) are lower and seem to drop off faster than the others.

The photon seems to be the most likely agent of non-ionizing character responsible for this production process. The case for the photon is supported by the rather frequent occurrence of events where a single, non-multiplying particle can be seen emerging from under an energetic cascade shower.

No cross sections can be computed because the top layer of 1-cm lead saturated the process. When 1-cm iron was substituted for the lead the production was of the same frequency, indicating saturation also in 1-cm iron.

The altitude dependence of this process was measured only for events where particles penetrating more than 6-cm lead (including 1 cm for the producing layer) were produced. The hourly rate was at Climax (11,500 feet) 7, at Idaho Springs (8600 feet) 28, at Denver (5300 feet) 25, and at Chicago 5, with an error of about 15 percent in each case. Because only processes at the high energy end of the energy distribution are selected here, one cannot conclude that there is a general maximum of this production process at an altitude as low as 8000 feet. But at lower altitude, the center of gravity of the energy distribution is definitely shifted to higher energies.

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Production of Secondaries in Paraffin by Primary Cosmic-Ray Particles

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Two high altitude balloon experiments were recently carried out for the purpose of measuring the secondary radiation which is generated in paraffin by penetrating cosmic-ray particles. Five different 4- and 5-fold coincidence circuits were used in each of these flights. Figure 1 shows the arrangement of the Geiger-Müller counters used in the flight of July 31, 1943. The 4-fold coincidence circuit *ABCD* measured the vertical intensity of cosmic radiation penetrating 8 cm of lead. ("*A*" consists of 3 counters connected in parallel.) The 5-fold set *EFACD* registered showers of 2 or more particles originating in the air above the apparatus. *GBCD* and *LBCD* measured the production of one or more particles in a layer of paraffin of 5 and 10 cm, respectively. Circuit *HKCD* measured the production of two or more particles in 10 cm of paraffin. The coincidences of the various counter sets were recorded by the same method as used in previous balloon experiments by one of the authors (Marcel Schein) in collaboration with W. P. Jesse and E. O. Wollan.[1] The coincidence pulses from the different circuits tripped separate neon lamps. The flashes of these neon lamps were photographically recorded on a sensitive film. Using this method, simultaneous coincidences in several of the counter circuits could be observed easily.

It was found in these experiments that in the upper atmosphere the circuits *GBCD*, *LBCD*, and *HKCD* were frequently tripped in coincidence with circuit *ABCD*. This means that at high altitudes a large fraction of the penetrating ionizing rays are accompanied by secondaries produced in the paraffin. A similar action of the penetrating component at sea level has not been found as yet. That the secondaries below the paraffin did not originate from the air above the apparatus is demonstrated by the fact that less than 3 percent of the coincidences *ABCD* were accompanied by a coincidence *EFACD*. This amounted to less than 7 percent of the multiples observed below the paraffin.

At an altitude corresponding to a pressure of 17 cm Hg, 15 percent of the vertical penetrating rays (*ABCD*) were accompanied by particles through any of the counters *G* and 35 percent by particles passing through any of the counters *L*. Correcting for the difference in solid angle between the counter set for the vertical penetrating rays and the counter sets for the radiation which produces the secondaries in paraffin one can say that 10 percent of the penetrating rays are accompanied by secondaries below 5 cm of paraffin and 20 percent below 10 cm of paraffin. The number of particles registered in circuit *HKCD* (two or more particles necessary for tripping this circuit) in coincidence with *ABCD* is considerably smaller than that in *LBCD*, which definitely shows that the secondaries are emitted in the forward direction with a small angular spread.

At higher altitudes similar measurements were carried out with a counter arrangement of slightly different geometry. The number of secondaries below the paraffin were measured up to an altitude corresponding to a pressure of 5.0 cm Hg. It was found that at a pressure of 6 cm Hg, 25 percent of the penetrating component is accompanied by secondaries below the paraffin, and that as many as 50 percent of the penetrating rays produce secondaries in 10 cm of paraffin. (These figures are again corrected for the difference in solid angle for the different counter telescopes.) This large number of secondaries below the paraffin indicates a cross section for production which is of the order of 10^{-24} cm^2, much larger than expected from the average area of the nuclei in paraffin.

Since the number of secondaries produced by mesotrons or electrons in paraffin is very small, it is obvious that the particles producing the large effect, which has been described above, cannot be of electronic or mesotronic nature. However, it seems highly probable that these particles consist of primaries since their number increases very rapidly with altitude close to the top of the atmosphere. It was previously assumed[2] that a multiple production of mesotrons should occur in nuclear collisions if the majority of the

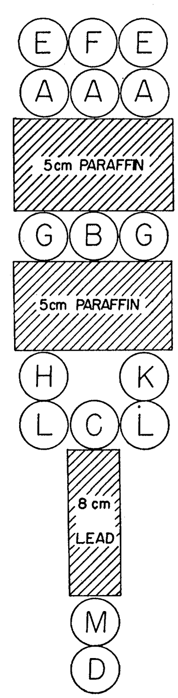

Fig. 1. Counter arrangement used in balloon flight.