and leads to widely differing results which are of considerable interest. We hope to extend this work to pressures of one atmosphere and higher, where it would be difficult to obtain pure gases in sufficient quantities.

Figure 1 is a reproduction of oscillograms which show some of the variations in results. All the effects are accurately reproducible. The figure was taken on a 1/100 second sweep; the voltage rises from zero to its maximum value and then falls to zero again, once for each sweep of either polarity. The maximum corona current corresponds approximately to the maximum tube voltage. Figure 1A shows the current flowing on the positive and negative half-cycles, 1180 volts crest, for a 1-cm gap between a 0.16 cm diameter hemispherically-ended tungsten point and a molybdenum plane in air at 0.57 cm Hg pressure (Apiezon oil manometer). Corona onset was at 670 volts negative and 970 volts positive. The current discontinuities reveal the presence of streamers on both polarities. With a 1-cm gap between a sharp tungsten point and a molybdenum plane in hydrogen at 0.14 cm Hg and an applied voltage of 635 volts crest, the streamers are present on the positive half-cycle only (Fig. 1B), whereas on the negative half-cycle the current is continuous (corona onset at 430 volts negative, 545 volts positive). No streamers are present for a discharge in oxygen at 1.52 cm Hg pressure in a copper cathode Geiger counter, of wire diameter 0.127 cm (tungsten) and cylinder diameter 2.54 cm, at

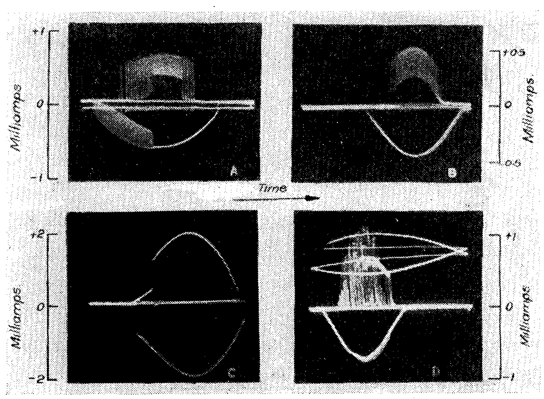

FIG. 1. Reproductions of oscillograms.

2330 volts crest (corona onset at 1370 volts negative, 1190 volts positive), when the discharge is disruptive on both polarities, as seen in Fig. 1C. The form of the discharge in the same counter when filled with CCl_2F_2 at a pressure of 0.69 cm Hg, and a 50-cycle timing wave, are shown in Fig. 1D (1560 volts crest). Many positive streamers are seen to be present whereas with a negative wire, the current is more or less continuous with indications of streamers near the crest (corona onset at 1050 volts negative, 1380 volts positive).

A detailed analysis of the results will be published in the near future.

We wish to thank Dr. A. P. M. Fleming, Director, Research and Education Departments, Metropolitan-Vickers Electrical Co. Ltd., for permission to publish this note.

[1] L. B. Loeb and A. F. Kip, J. App. Phys. **10**, 142 (1939).
[2] A. F. Kip, Phys. Rev. **54**, 139 (1938); **55**, 549 (1939).
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The Multiple Production of Secondary Cosmic-Ray Particles in the Lower Atmosphere

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A DETAILED study of secondary processes of the cosmic radiation was made at altitudes between sea level and 14,000 feet. The instrument consisted of 125 counter tubes placed above and between six layers of lead *A* to *F* (Fig. 1), which are 1, 5, 5, 5, 9, 10 cm thick,

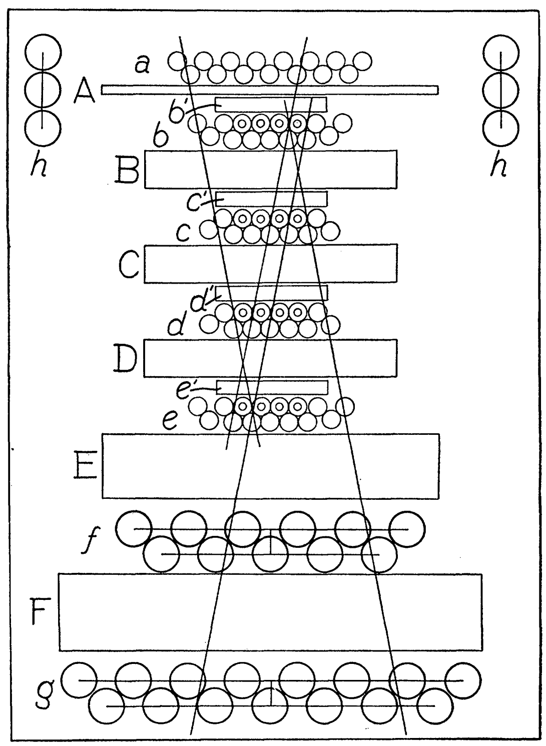

FIG. 1. Schematic diagram of the arrangement of counters and absorbers.

respectively. The counter tubes of groups *a* to *e* are individually connected to one indicating neon lamp each. All neon lamps are arranged on a panel in places corresponding to the actual positions of the counter tubes to which they belong. A "master pulse" flashes a neon lamp for the duration of 0.5 sec., provided that a particle coincident with the master pulse (resolving time 10^{-5} sec.) traversed the counter tube to which the neon lamp belongs. The ring-marked counters and six counters in each group

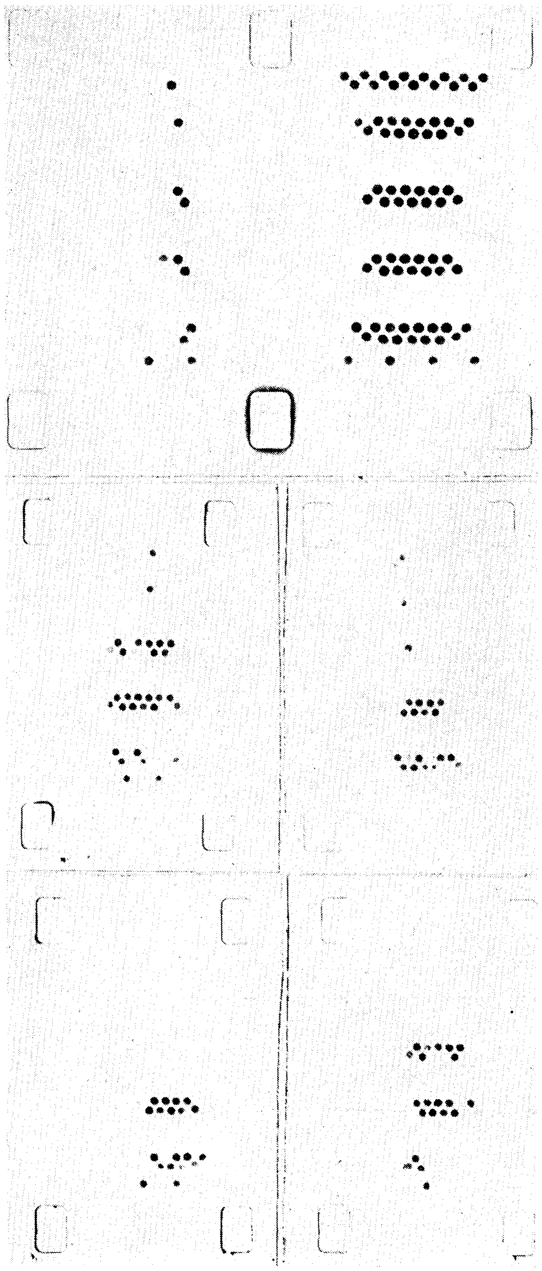

FIG. 2. Photographs of the neon lamps enlarged from 16-mm film. The pictures in the center and at the bottom are typical for the multiple production process.

b' to e' (oriented at a right angle with the other counters) set off a master pulse whenever a vertical particle penetrates at least *one* of the absorbers B, C, or D. The master pulse also operates the automatic camera. Figure 2 (top, right) shows a photograph taken when all neon lamps were flashed artificially. The four neon lamps at the bottom of this picture are connected to counter groups h, f, g, and to an additional tray of counters placed about two meters away from the instrument.

Altogether, 200,000 pictures were taken on Mt. Evans in September, 1941, and between Climax, Colorado (11,500 feet), and Chicago, in January, 1942. Besides single mesotrons (Fig. 2, top, left) and cascade showers, two distinct processes of production of secondary particles were observed.

In the first process, a neutral radiation produces in the top layer A of 1-cm lead *single, non-multiplying* particles mostly of a range below 5-cm lead. A detailed account of this process is given in the following letter.[1]

In the second process, the produced particles invariably come in showers; one-tenth of the observed production processes are initiated by penetrating *ionizing* rays, nine-tenths by penetrating *non-ionizing* rays. Figure 2 (center and bottom) gives typical examples. Production processes initiated by penetrating neutral particles have been reported previously.[2]

Absorbers of 5-cm iron, aluminum, carbon, and paraffin were alternated with lead in positions B and C at Climax. The ratio of the frequency of production in B to the frequency of production in C affords a rough determination of the cross section of the process.[3] The hourly rate (the standard error averages 10 percent) of the production in B and C and the cross sections per nucleus in 10^{-24} cm^2 are:

	Pb	Fe	Al	C	H	Paraffin
B	13.5	18.5	26	20		20
C	10.5	6	15	12		8
Cross Section	1.5	2.7	1.8	2.0	1.5	

The cross sections of light nuclei observed here agree with those observed with fast neutrons as projectiles, but no increase of cross section is observed for heavy nuclei. Processes initiated by ionizing rays show approximately the same cross section, multiplicity, and energy as those initiated by non-ionizing rays. Neutrons and protons may be the particles initiating these processes. The multiple production of mesotrons by ionizing, non-shower-producing particles (protons) reported by Schein, Jesse, and Wollan[4] and discussed by Carlson and Schein[5] may well be identical with the present process (the cross section of the latter is an order of magnitude larger than the one estimated by Carlson and Schein).

The range of the produced particles averages 10-cm lead for those produced in light materials and increases up to 30-cm lead for particles produced in lead. With the data available so far, an unambiguous conclusion as to the significance of this result cannot be reached.

The altitude dependence of the production in lead was measured between Climax and Chicago. The rate of production drops rapidly below Climax to one-third at Idaho Springs (8600 feet), to one-fourth at Denver (5300 feet), and to one-seventh at Chicago. The production cross section for nitrogen and oxygen to be expected from our data would lead to an absorption ten times faster than this. We must therefore assume that these particles are themselves of secondary origin and that they might be identified as neutrons and protons produced by the photons of the soft component.[6]

The writer wishes to express his deep appreciation to

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[1] V. H. Regener, Phys. Rev. **64**, 252 (1943).
[2] F. R. Shonka, Phys. Rev. **55**, 24 (1939); M. Schein, E. O. Wollan, and G. Groetzinger, Phys. Rev. **58**, 1027 (1940); B. Rossi and V. H. Regener, Phys. Rev. **58**, 837 (1940); V. H. Regener and B. Rossi, Phys. Rev. **59**, 113 (1941).
[3] Since it is rather certain that we have to deal with the production of rays of various energies, the assumption has been made that the cross section for the production process is in first approximation independent of energy.
[4] M. Schein, W. P. Jesse, and E. O. Wollan, Phys. Rev. **59**, 615 (1941).
[5] J. F. Carlson and M. Schein, Phys. Rev. **59**, 840 (1941).
[6] S. A. Korff and E. T. Clarke, Phys. Rev. **61**, 422 (1942); see also reference 1.

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 detected 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.

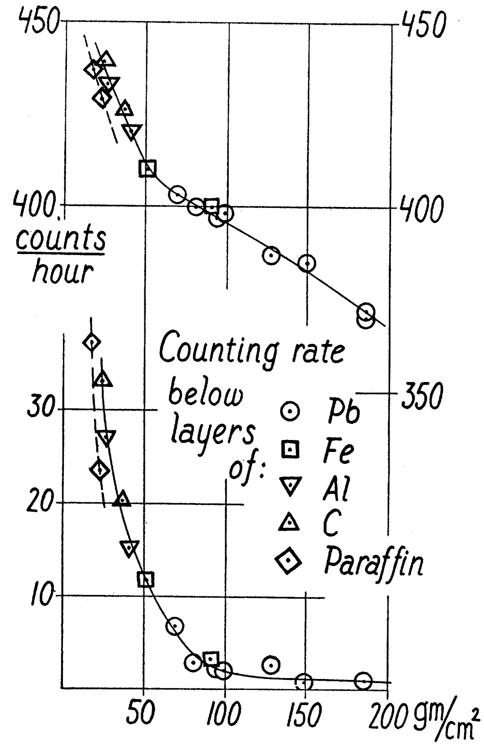

FIG. 1. Above: An absorption curve of non-multiplying cosmic rays at Climax (11,500 feet). Below: An absorption curve of slow protons produced by non-ionizing rays in 1-cm lead at Climax. The experimental error is to be inferred from the scattering of the values about the curves

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

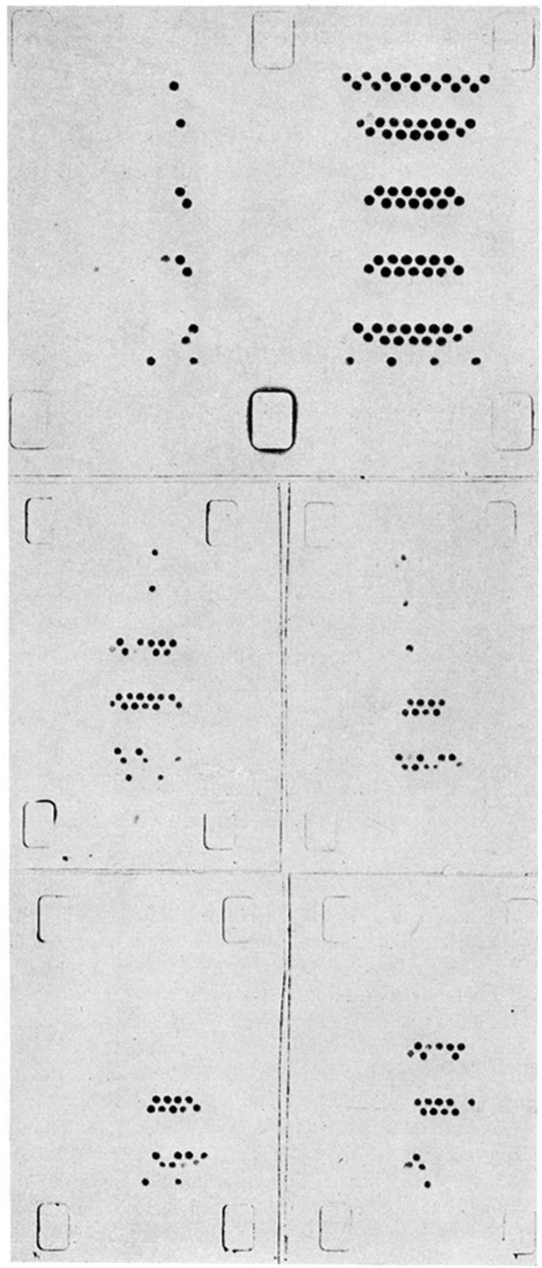

FIG. 2. Photographs of the neon lamps enlarged from 16-mm film. The pictures in the center and at the bottom are typical for the multiple production process.