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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[1] V. H. Regener, Phys. Rev. **64**, 250 (1943).
[2] M. Schein and V. C. Wilson, Phys. Rev. **54**, 304 (1938); M. Schein, W. P. Jesse, and E. O. Wollan, Phys. Rev. **57**, 847 (1940); see also reference 1 and the papers cited there.
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[4] C. E. Nielsen and W. M. Powell, Phys. Rev. **63**, 384 (1943).

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

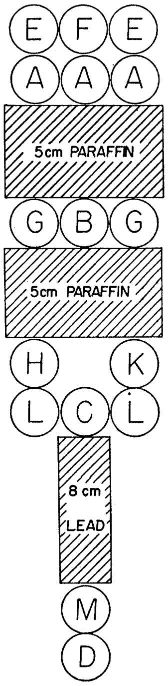

FIG. 1. Counter arrangement used in balloon flight.

primaries were protons. This would be in good agreement with the results of the present experiments, which seem to show that at high altitudes part of the penetrating component consists of particles which are accompanied by secondaries after passing through paraffin. The existence of such an effect in paraffin is characteristic for the primary cosmic radiation and is so far the only specific property exhibited by primaries which makes their identification possible.

The evaluation of the present experiments indicates a decrease in proton intensity from the top of the atmosphere (zero pressure) to a pressure of 6 cm Hg by a factor of 2.2 and to a pressure of 17 cm Hg by a factor of 7.5. This decrease leads to an absorption with a cross section of 2×10^{-25} cm^2. This cross section is approximately equal to the area of a nitrogen or oxygen nucleus and shows that the primaries are absorbed in air by nuclear processes.

The authors wish to express their appreciation to Dean A. H. Compton for his continued interest in these experiments.

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The Origin of Large Bursts Under Thick Shields

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A HIGH pressure model C ionization chamber was used to record cosmic-ray bursts containing more than 100 particles. Surrounding the chamber (Fig. 1) was a uniform hemispherical shield of 35 cm of iron equivalent to 12 cm of lead in terms of radiation units. It has been pointed out by several authors that large bursts under 20 radiation units of material are very probably produced by the mesotron component of cosmic rays. Since the high energy mesotrons (energies greater than 10^{10} ev) which produce bursts of more than 100 particles under thick shields show a distribution which is roughly independent of the zenith angle, it is quite necessary to shield the ionization chamber with a uniform hemisphere of material in order to obtain results which are consistent. The scattering of shower electrons in the shielding material likewise makes it imperative that a good geometry be used for the shield.

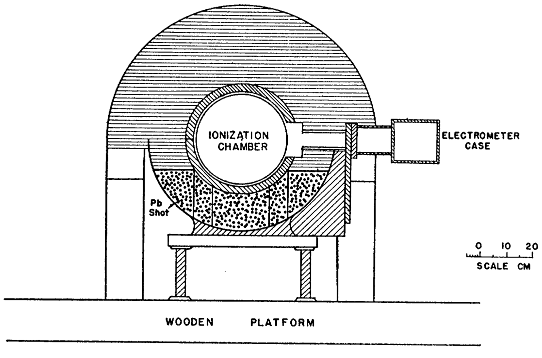

FIG. 1. Details of the 35-cm iron shield.

The burst data in 35 cm of Fe were compared with the burst data of Schein and Gill[1] obtained at sea level with a similar ionization chamber shielded with 12 cm of lead. This comparison shows that the size of large bursts of energy greater than 5×10^{10} ev depends approximately on the square of the atomic number of the shielding material in which the bursts are produced. This is in agreement with the cascade theory of bursts according to which these bursts are described as photon-initiated showers in the chamber shield; the photon initiating the shower is produced by the bremsstrahlung process of the incident mesotron. Christy and Kusaka[2] have shown that for burst production by mesotrons, the bremsstrahlung process is the most probable for mesotrons of energy greater than 5×10^{10} ev.

Recent experiments[3] were carried out in Chicago with an unshielded ionization chamber operated "in coincidence" with 5 sets of G-M counter coincidence units so arranged that each had a high probability of detecting extensive atmospheric (*A* showers) showers. It was found that when there was a negligible amount of heavy material surrounding the ionization chamber practically all the observed bursts of more than 100 particles were accompanied by a simultaneous discharge of the G-M counters. Thus these experiments prove that a large burst observed in the unshielded ionization chamber is in reality the high density region of an *A* shower. According to the theory of *A* showers the dense part (core) of such a shower should contain particles of very high energy. It might therefore be anticipated that at least a large fraction of the core particles in *A* showers should be able to traverse considerable thicknesses of heavy material. The amount of material traversed by these core particles should then give a rough measure of their energy. The experiments carried out with 12 cm of lead around the ionization chamber show that only 4 to 7 percent of the bursts are coincident with *A* showers as detected with G-M counters. While there are thus relatively few *A* showers which produce bursts under 12 cm of lead, there is definite evidence that some of the *A* showers have cores containing particles which traverse 12 cm of lead. An electron or photon must have more than 10^{10}-ev energy in order to traverse 12 cm of lead and appear below that thickness of material as a single particle; if it is to traverse this material and emerge below it with a multiplication of 100 particles, it must have an energy several times 10^{11}. The experiments with the unshielded chamber[3] have shown that *A* showers have particle densities in the core up to 30,000 particles per square meter. If one is to interpret the present results correctly, one must assume that at sea level the great majority of the particles in the core of an *A* shower producing bursts under 12 cm of lead have less than about 10^{11}-ev energy.

Having thus obtained experimental evidence for the nature of the bursts both for the unshielded case and for the 12-cm Pb shielded case, it is necessary to investigate the origin of the bursts which occur under an intermediate thickness of shielding material. It is well known from