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.

[1] M. Schein, W. P. Jesse, and E. O. Wollan, Phys. Rev. **59**, 615 (1941).
[2] J. F. Carlson and M. Schein, Phys. Rev. **59**, 840 (1941).

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.

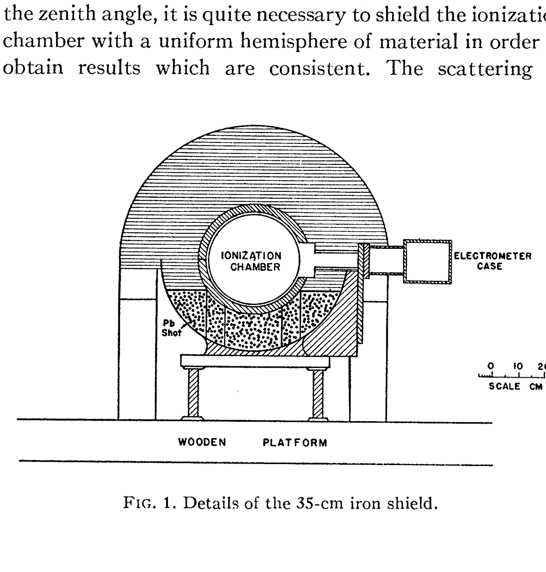

Fig. 1. Details of the 35-cm iron shield.

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 transition curves that bursts exhibit a maximum frequency at a thickness of shielding material equivalent to about 7 radiation units. These experiments are in progress with a 12-cm iron shield (about 7 radiation units).

[1] M. Schein and P. S. Gill, Rev. Mod. Phys. **11**, 267 (1939).
[2] R. F. Christy and S. Kusaka, Phys. Rev. **59**, 414 (1941).
[3] R. E. Lapp, Phys. Rev. **64**, 129 (1943).

On the Spin of the Mesotron from Burst Measurements

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September 9, 1943

In an accompanying Letter,[1] it has been pointed out that the large bursts observed under thick (i.e., 20 radiation units) shields of heavy material are chiefly produced by mesotrons. The contribution of A showers to these bursts is of the order of 4 to 7 percent of the total burst frequency and for the purposes of this discussion, can be neglected. Through the generous cooperation of Dr. Jno. A. Fleming of the Carnegie Institution, the extensive burst data obtained at the Cheltenham Cosmic-Ray Station (72 meters elevation) were made available to the writer. These data were obtained with a Carnegie model C ionization chamber shielded with a uniform layer of lead shot equivalent to a solid 10.7-cm lead shield. From an analysis of the data, an integral size-frequency distribution curve was constructed as shown by the experimental points in Fig. 1. The large amount of data available at Cheltenham allows for a small statistical error for bursts containing even 1000 or more particles; the accuracy of the experimental points is illustrated by the small statistical error drawn for each point. Here the absolute burst frequency N (number of bursts greater than size S per square cm per sec.) is plotted against the product βS where β is the critical shower energy characteristic of the shielding material, and S is the size of the burst in number of particles. On the same graph, three additional curves have been plotted; these are the theoretical curves for burst production by spin 0, $\frac{1}{2}$, and 1 mesotrons, respectively, as calculated by Christy and Kusaka.[2] It is seen that the experimental data are apparently in excellent agreement with the theoretical spin 0 curve. However, certain factors[3] which enter into the theory possibly introduce an uncertainty into the theoretical results so that it is not certain at present whether spin $\frac{1}{2}$ can be eliminated from consideration. For example, the present agreement between theory and experiment is obtained on the basis of an assumed mesotron mass of 177 m_e (m_e=mass of the electron); however, calculation shows that the mesotron mass of 230 m_e would yield a theoretical curve for spin $\frac{1}{2}$ which would be in fair agreement with the burst data.

While it does not seem possible to distinguish between spin 0 or $\frac{1}{2}$ on the basis of the present data, it is possible to state that the existence of a spin 1 mesotron at sea level is definitely ruled out by the experimental evidence. The marked increase in frequency of large bursts as a function

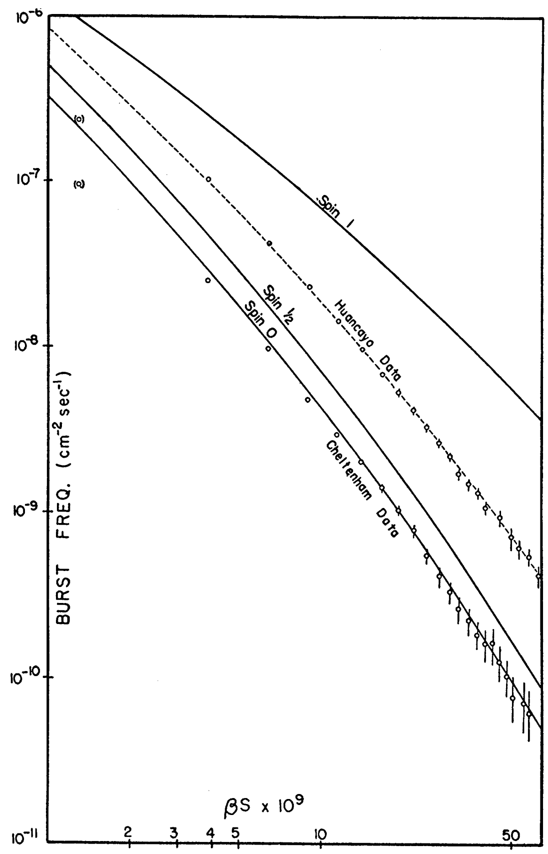

FIG. 1. Integral size frequency distribution curves. The burst frequency per square cm per second is plotted against the product of S where β is the critical shower energy of the shielding material, and S is the number of particles in the burst. The curves labeled spin 0, $\frac{1}{2}$, and 1 are the theoretical curves for burst production by mesotrons as given by Christy and Kusaka.

of altitude has been pointed out by Schein and Gill.[4] An analysis similar to that obtained from the Cheltenham burst data has been carried out for the burst data obtained at the Carnegie station at Huancayo, Peru (3350 meters). From the analysis a size-frequency distribution curve was plotted as shown in Fig. 1. Since the mesotrons giving rise to the bursts under thick shields at Huancayo were due to mesotrons of the same kind as are present at sea level, there should be no increase in the burst frequency with increasing altitude, for the high energy mesotrons are absorbed very little in traversing the atmosphere between Huancayo and sea level and are therefore just as numerous at sea level as at high altitude. There are two explanations possible for this observed increase with altitude. The first and more probable explanation is that at high altitude the cores of A showers (extensive atmospheric showers) penetrate 12 cm of lead and produce the majority of these bursts. This explanation is given additional credence by the evidence presented in the accompanying letter. Furthermore, the marked increase of A showers with altitude as found by Auger and Hilberry indicates that the increase in burst