Slow Mesons in Cosmic Radiation

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Using Bhabha's method, the intensity of slow mesons is determined. The intensity of mesons of energy greater than 10^8 ev and less than 2.7×10^8 ev is 6 percent of the total meson intensity. Near the geomagnetic equator, the total intensity increases by 54.4 percent, the meson intensity by 21.7 percent, and the electron intensity by 162.1 percent when the altitude increases from 3100 ft. to 7200 ft. The electron intensity, which is about 25 percent of the meson intensity at 3100 ft., increases to 50 percent of the meson intensity at 7200 ft.

THE behavior of cosmic-ray electrons is explained satisfactorily by the cascade theory. On the basis of this theory, very few, if any, of the primary electrons incident on the top of the atmosphere can reach sea level. Experimental results, however, indicate clearly that a significant part of cosmic radiation at sea level, and even at great depths, consists of electrons. It is believed that most of these electrons in the lower atmosphere arise out of meson decay.[1] The test of the correctness of any theory of meson decay ultimately depends on an accurate determination of the proportions of electrons and mesons in cosmic radiation.

One method of determining this ratio of electron to meson component is by a statistical examination of the tracks obtained in a Wilson chamber. For high accuracy, a large number of photographs are required. It is not possible to distinguish mesons of all energies from electrons by their tracks in a Wilson chamber.[2,3] Stray photographs of low energy mesons may be obtained but this fact can only be utilized to indicate the presence of very low energy mesons in cosmic radiation.

The second method is by the use of Geiger counters. With a counter telescope, the total electron and meson intensity can be determined. (The intensity of protons, etc., if present can be considered to be negligible and, for purposes of this paper, will be included in the meson component.) By introducing an absorber like lead between the counters of a counter telescope, electrons can be absorbed and the meson intensity determined. The difference between the total and the meson intensity gives the electron intensity. This method has its obvious handicaps. If small thicknesses of lead are used to absorb electrons, some of the high energy electrons are not cut out and are included in the meson component. If large thicknesses of lead are used for the purpose, low energy mesons are absorbed and they will be included in the electron component. Mesons of energy, 3×10^8 ev can, according to Rossi and Greisen,[4] penetrate 21.76 cm of lead. Lead absorbers of thickness up to this value have been used in estimating the meson intensity. Therefore, it is usual to call all mesons of energy less than 3×10^8 ev as "slow" mesons. Mesons of higher energy are called "fast" mesons.

If the absorption curve of slow mesons is determined, it is possible to obtain the ratio of electron to meson intensity from the results of the usual experiments. Besides, the intensity of slow mesons of different energies can be determined. In recent years, attempts have been made to determine the intensity of slow mesons. Auger[5] and Greisen[6] make use of the differential absorption of electrons and mesons in the same equivalent thickness of different materials like lead, carbon, aluminum, etc., to arrive at an estimate of slow meson intensity. Auger's results are subject to considerable error. Greisen's analysis is a very elegant one, and his results are in good agreement with the results reported in this paper. But such a method is an indirect one, and an

[1] Euler and Heisenberg, Ergeb. d. exact. Naturwiss **17**, 1 (1938).
[2] Blackett, Proc. Roy. Soc. **A165**, 11 (1938).
[3] S. H. Anderson and C. D. Nedermeyer, Phys. Rev. **51**, 884 (1937); **54**, 88 (1938).
[4] B. Rossi and K. Greisen, Rev. Mod. Phys. **13**, 240 (1941).
[5] P. Auger, Phys. Rev. **61**, 684 (1942).
[6] K. Greisen, Phys. Rev. **63**, 323 (1943).

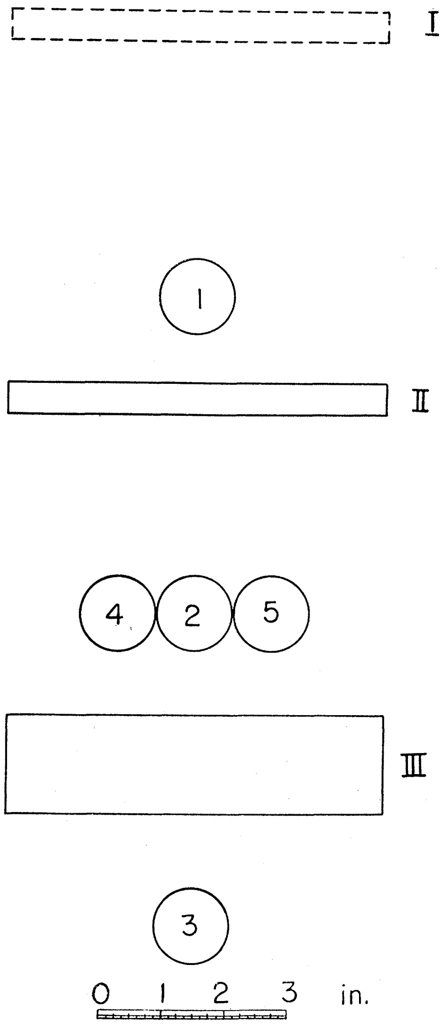

FIG. 1. Arrangement of counters.

estimate of the slow meson intensity by a more direct method is, therefore, desirable. Schein and others[7] and Sarabhai[8] cut out electrons while measuring the meson intensity by not recording particles which produce showers in small thicknesses of lead. It has been pointed out by Bhabha[9] that a good fraction of low energy electrons produce showers of very few particles, often only of one and that this fraction cannot be cut out by just not registering the shower-producing particles. This fact has also been experimentally verified by one of us.[10]

Any attempt to estimate the intensity of "slow" mesons must be free from the objections indicated. In addition, the results must be free from the effects of side showers. In order to minimize the possibility of chance coincidences, it is desirable to avoid a double coincidence system. Impelled mainly by these considerations, an attempt has been made here to give a report of a new approach to the problem made possible by the method developed by Bhabha.[9]

EXPERIMENTAL ARRANGEMENTS

A counter telescope designed on the basis of Bhabha's method is shown in Fig. 1. Counters *1*, *2*, and *3* were connected in coincidence and form the vertical telescope. Counters *4* and *5* were connected in parallel and in anticoincidence with counters *1*, *2*, and *3*. The pulse was taken from the copper cylinders of counters *4* and *5* for anticoincidence and these counters were shielded. Each of the counters used was 6 in. long and $1\frac{1}{4}$ in. in diameter. This type of counter telescope gives results free from the effect of side showers.[10]

Positions I, II, and III were for placing lead. High energy electrons produce showers in 1.25 cm of lead placed in position II and are cut out by the shower particles tripping the counters 4 or 5 or both. Lead in position II loses a good deal of its significance when lead is placed in position I. Even under such conditions, lead was placed in position II, for purposes of maintaining identical geometrical conditions for all measurements. Lead placed in position III was for absorbing low energy electrons. Lead completely covering the solid angle was placed in position I for absorption measurements. As penetrating non-ionizing cosmic rays form a negligible fraction of the total

TABLE I. Measurements of intensity.

No.	Lead I	Lead II	Lead III	Total lead	Counts	Time in hours	Counts/hour
1	—	—	—	—	4497	38	118 ±1.2
2	—	—	5.25	5.25	5058	52	97.3 ±0.9
3	—	1.25	4.00	5.25	7680	81	94.8 ±0.7
4	5.2	1.25	4.00	10.45	4826	52	92.8 ±0.9
5	9.3	1.25	4.00	14.55	6905	76	90.8 ±0.7
6	13.7	1.25	4.00	18.95	5430	61	89.0 ±0.8

[7] Schein, Jesse, and Wollan, Phys. Rev. **58**, 1027 (1940).
[8] V. Sarabhai, Proc. Ind. Acad. Sci. **19**, 37 (1944).
[9] H. J. Bhabha, Proc. Ind. Acad. Sci. **19**, 23 (1944).
[10] Chandrashekhar Aiya; Proc. Ind. Acad. Sci. (in print).

intensity[11] and as scattering can be considered negligible for purposes of the accuracy aimed at, this choice of position I for lead in absorption measurements is not objectionable.

The measurements taken are given in Table I. From observations 3, 4, 5, and 6, a graph is drawn and is shown in Fig. 2. This gives the absorption curve of slow mesons. It is extrapolated to zero thickness by dashes.

DISCUSSION OF THE RESULTS

No. 1 represents the total intensity. If we assume that No. 3 gives the meson intensity, the electron intensity is 23.5 ± 1.9 counts/hour. Therefore, at Bangalore (geomagnetic latitude $=3.3°$N and altitude $=3100$ ft. above mean sea level) cosmic rays consist of 80 percent mesons and 20 percent electrons. It will be clear from the discussion which follows that No. 3 gives the meson intensity to an accuracy of 2 percent and, therefore, the ratio of electron to meson intensity stated above is accurate to within 2 percent. The difference between No. 2 and No. 3 represents the fraction of electrons cut out by splitting the lead as suggested by Bhabha. It is 10.6 ± 6.8 percent of the total electron intensity.

According to Bhabha, the fraction of electrons which penetrates 5.25 cm of lead and which does not produce adequate showers to trip counters 4 or 5 or both is at the most 2 percent of the total electron intensity. Therefore 0.47 count in 94.8 ± 0.7 counts/hour represents the electron intensity registered as mesons in observation No. 3. This is within the limits of accuracy of the measurement. Consequently it is correct to say that No. 3 gives the intensity of mesons which penetrate 5.25 cm of lead. Observations 4, 5, and 6 give the meson intensities to a still better degree of accuracy. Therefore, the graph drawn with these observations represents the absorption curve of slow mesons. By making use of this graph and the curves of Rossi and Greisen,[4] we can deduce the intensity of mesons within different energy limits. Thus, it is found that slow mesons of energy greater than 10^8 ev and less than 2.7×10^8 ev is about 6 percent of the total meson intensity.

[11] Janossy and Rochester, Proc. Roy. Soc. **A181**, 399 (1943).

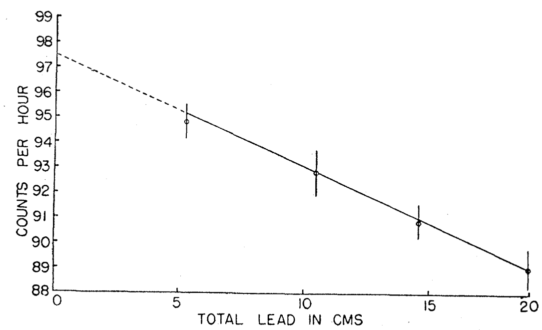

FIG. 2. Absorption of slow mesons.

One of us[12] has reported something abnormal in the behavior of mesons of energy in the region of 3×10^8 ev, and the subject is yet under investigation. It is, therefore, not proposed to go into the question of mesons of this energy here.

The curve given by Euler and Heisenberg[1] for the energy spectrum of mesons shows that mesons of energy less than 10^8 ev constitute about 2 percent of the total meson intensity. The smallness of this fraction is due to the collision loss of mesons which increases rapidly below this energy. If our graph were extrapolated to zero thickness, which is clearly not justified for the reason just mentioned, we would find that about 2.7 percent of the total meson intensity consists of mesons of energy less than 10^8 ev. This is natural. The meson absorption curve for thicknesses of lead less than 5.25 cm must fall off towards the X axis, i.e., must be below the dotted line in Fig. 2. Although it is not conclusive, it may be pointed out that the point for 5.25 cm of lead having a higher statistical accuracy than others is below the line and can be taken to indicate that the curve does fall off as is to be expected. The percentage of mesons absorbed in the first 5.25 cm of lead, i.e., of energy less than 0.93×10^8 ev is very small (less than 2 percent of the total intensity), and it is difficult to estimate this small quantity by obtaining readings of meson intensity only within the first 5.25 cm of lead as any method used does not entirely cut out electrons and the fraction of electrons not cut out increases with decreasing thickness of lead.

It would, however, be possible to obtain an *upper limit* to the meson intensity at 1.25 cm of lead by omitting the 4.0 cm of lead absorber.

[12] Chandrashekhar Aiya, Nature **153**, 375 (1944).

TABLE II. Comparison of results at 3100 ft. and 7200 ft.

Component	Intensity at 3100 ft. in counts/hr. (Bangalore)	Intensity at 7200 ft. in counts/hr. (Ootacamund)	Percent increase corresponding to a rise in altitude of 4100 ft.
Total	118.3	182.7	54.4
Mesons	94.8	121.1	21.7
Electrons	23.5	61.6	162.1

Sarabhai[8] has done this with 2 cm of lead. Since the intensity of the soft component is 25 percent of the meson intensity at Bangalore and we can gauge from the figures given by Bhabha[9] that very roughly about 10 percent of the soft component passes through this thickness without producing showers, it follows that the soft component would contribute about $2\frac{1}{2}$ percent to the meson reading so obtained. But it is quite clear that such a measurement would have no meaning if taken at an altitude of 7200 ft. where the soft component intensity is 50 percent of that of the hard component and, at still greater altitudes the error would be much greater.

The graph in Fig. 2 holds for the solid angle of the counter telescope used by us and indicated in Fig. 1, which is drawn to scale. For different solid angles, a part of the mesons at least will have traveled through different distances in the atmosphere and suffered different degrees of losses of energy. It is, therefore, not quite impossible that the absorption curve may be *slightly* different for different solid angles, but this is a matter for investigation.

The counter telescope used for experiments at Ootacamund (geomagnetic latitude = 1.7°N and altitude = 7200 ft. above mean sea level) by one of us (S.V.C.) was quite similar to the one used here. The results at the two places can be utilized to indicate the variation of the different components with altitude near the geomagnetic equator. This is done in Table II.

The electron intensity which is about 25 percent of the meson intensity at 3100 ft. increases to 50 percent of the meson intensity at 7200 ft.

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