Nature of the Soft Component of Cosmic Rays at 3500 Meters Altitude

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An interpretation is given for the absorption curves of cosmic rays obtained with screens of different atomic numbers. Measurements made in 1935 at the Jungfraujoch (3500 m) with lead and aluminum show the existence of an important number of mesons of relatively small energy in the soft component.

DIFFERENTIAL ABSORPTION OF ELECTRONS AND MESONS

IT has been recently shown[1] that the soft component of cosmic rays, constituted of the particles which are completely absorbed in 15 or 20 cm of lead, does not contain exclusively electrons but also slow mesons. A separation of these two parts, electronic and mesonic, can be attempted by the use of absorbents of very different atomic numbers such as lead and aluminum. The energy losses of the mesons, which are only due to collision (ionization) processes, will be approximately proportional to the number of electrons per cubic centimeter of absorbent, $Z\rho/A$, where ρ is the density, Z the atomic number, and A the atomic weight. This will be also true for electrons if their energy is below the critical value for the type of matter considered, but not for electrons with a higher energy. In this last case the losses will be due mainly to radiative processes, and will depend upon the atomic number by a factor of Z^2.

The thickness of aluminum equivalent to 1 cm of lead for collision processes alone is 3.4 cm, so that the 8 cm of lead which absorb the larger part of the soft component are equivalent to 27 cm of aluminum. On the other hand, *electrons* of 10^9 volts, which are practically stopped by 4 cm of lead, would lose only a fraction of their energy in $4\times 3.4=13.6$ cm aluminum, and would not be stopped by half a meter of this metal.

MEASUREMENTS FOR LEAD AND ALUMINUM

The curves in Fig. 1 represent results obtained in 1935 at the International Laboratory of Jungfraujoch, Switzerland, with a triple coincidence counter set arranged in vertical telescope.[2] Screens of lead and aluminum could be interposed up to 20 cm thickness. Curves marked Pb and $\mathrm{Al_I}$ give the mean number of counts N per hour as a function of the thickness of the screen for these two metals.

The results for aluminum have been then reduced to the equivalent thicknesses of lead for collision processes. The difference between the new curve, marked $\mathrm{Al_{II}}$, and the Pb curve is due only to the particles showing radiative losses, that is to say, electrons with an energy surpassing notably the critical value for lead. Consider for instance the point for 8 cm Pb, marked N': no electron of reasonable energy (less than 10^{10} ev) can give an effect beyond such a screen. The corresponding point on $\mathrm{Al_{II}}$ is situated 30 counts higher: this means that 30 particles per hour are electrons of sufficient energy to traverse 27 cm of aluminum, i.e., electrons of 10^8 volts or more. The group of particles so defined represents 8 percent of the total number and 18 percent of the soft group. A vertical shift of the $\mathrm{Al_{II}}$ curve ($\mathrm{Al_{III}}$) brings N and N' in coincidence and the compound curve $O'M'N'R$ obtained represents the absorption of the particles which do not show important radiative losses in aluminum, that is: mesons, and electrons under 10^8 volts.

SLOW MESONS AND ELECTRONS

The lead curve after 20 cm can be considered as practically linear on the scale of Fig. 1. The prolongation toward the origin would give the line RS, so that the point S represents the dividing point between the soft and the hard components. The respective percentages of these components are 46 percent and 54 percent of the

[1] M. Schein, E. O. Wollan, and G. Groetzinger, Phys. Rev. **58**, 1027 (1940); G. Herzog and W. H. Bostick, Phys. Rev. **59**, 122 (1941).

[2] Pierre Auger, L. Leprince-Ringuet, and P. Ehrenfest, J. de Physique [7] **7**, 58 (1936).

total.[3] The hard component contains practically only mesons of larger energies (more than 2.5×10^8 ev). The portion of the soft component absorbed between 8 cm and 20 cm on the lead curve ($N'N''$) contains slower mesons, their energies being comprised between 10^8 and 2.5×10^8 ev: they represent 15 counts, or about 4 percent of the total, and 9 percent of the soft component.

From O' to N' our curve is the reduced Al curve, N' corresponding to the absorption by 27 cm Al. Here slow mesons and electrons are absorbed simultaneously, and the interpretation is more uncertain. But let us consider the point M on the lead curve[4] corresponding to 2.5 cm Pb. The electrons below 10^8 are practically all stopped in that screen, so that MM'' will be equal to the number of slow mesons unabsorbed by 2.5 cm Pb plus the number of electrons above 10^8 ev. But this last number is given by NN' or by MM' which is equivalent so that by subtraction $M'M''$ gives the number of slow mesons. We find only thus a minimum value for this number, because we should add the very slow mesons absorbed by 2.5 cm lead. These particles, which have less than 50 million volts energy, produce more ions per cm than the more energetic electrons or mesons, so that their number can be inferred from the number of thick tracks observed on the cloud-chamber photographs obtained at high altitude. This number, from our own observations on Jungfraujoch and from Anderson's on Pike's Peak, is of the order of 1 percent or 2 percent of the total number of particles. This, added to the value of $M'M''$, gives 60 counts, or 16 percent of the total. We may split this slow meson component into one group with energies below 10^8 and the group with energies between 10^8 and 2.5×10^8 already recognized. By subtraction the first group is found corresponding to 45 counts, or 13 percent of the total and 28 percent of the soft component.

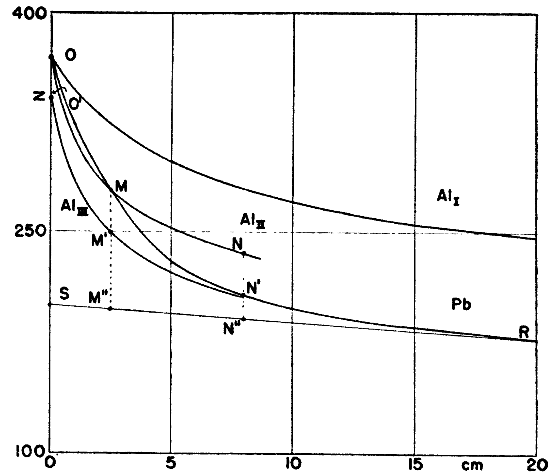

FIG. 1. Absorption curves of the soft component of cosmic rays obtained at 3500 m altitude for lead and aluminum. N is the mean number of counts per hour, plotted against the thickness of the absorber, in centimeters.

Now only the electrons with less than 10^8 ev have not been counted in our balance; because of the thickness of the counter walls (5 mm Cu) no electron of less than 10^7 ev can give a coincidence. So the group of electrons between 10^7 and 10^8 represents the remaining 78 counts of the soft component, i.e., 21 percent of the total. Table I summarizes these results. The accuracy of the numbers given here is unfortunately rather low, especially in the case of values obtained by subtraction. So the number of mesons below 10^8 ev and the number of electrons between 10^7 and 10^8 ev are probably correct only to ±25 percent. The numbers of electrons and mesons above 10^8 ev may be correct to ±15 percent.

TABLE I. Approximate constitution of the soft component at 3500 m altitude.

Particles	Energy (ev)	Number per hour	Percentage in total	Percentage in soft component
Mesons	$>2.5\times10^8$	200	54	—
Mesons	10^8 to 2.5×10^8	15	4	9
Mesons	$<10^8$	45	13	28
Electrons	$>10^8$	30	8	18
Electrons	10^7 to 10^8	78	21	45

[3] A small correction should be introduced by the consideration of the air showers which are frequent at high altitudes; they are not absorbed by the interposed screens, and the counts which they produce are added to the hard component.

[4] From that point on the Pb and Al$_{II}$ curves diverge strongly; in fact, they cross each other, but this is not significant.