1º P.R.: original

ON THE ABSORPTION OF PENETRATING SHOWERS

H.A.Meyer, G.Schwachheim and A.Wataghin

Departamento de Fisica

Universidade de São Paulo

São Paulo Brasil

SUMMARY

Several experiments on the absorption in lead of the particles of penetrating showers have been performed under different geometrical conditions. The penetrating showers produced in air are shown to have a high penetrating power whereas those produced locally are strongly absorbed. An interpretation is given by the study of the selection of the penetrating showers by our apparatus. The cross-section for nuclear absorption of the pi-mesons of the locally produced penetrating showers was measured and shown to be smaller than half the geometrical one. Some data on the structure of the PS and on the presence of photons were obtained.

INTRODUCTION

A series of experiments was performed in order to study the absorption of the ionising particles of penetrating showers (PS). We studied the absorption in lead of the particles of the PS produced in the air as well as those produced in a material located above the arrangement. We call the former atmospheric PS and the latter local PS. The frequency of atmospheric PS is given by the registered (recorded) frequency without the producing material (background), since accidental coincidences and coincidences due to mesons and their knock-on secondaries are negligible [1]. Moreover, the lead shields are thick enough to absorb soft showers (a point that is checked in each experiment) and the position of these shields is such that the registration of a PS produced in them would be very improbable. As we observed that the absorption of the atmospheric PS is very small in general, their absorption in the producing material will be small and the frequency of local PS will be given by the difference between the frequencies with and without the producing material.

Experiment I was performed in Campos do Jordão (844 g/cm^2) during the last months of 1949. The other ones (others) were performed in São Paulo (950 g/cm^2) in 1950. The G.M. counters used in our experiments, [redacted] with sensitive area of [redacted] 2,9 cm x [redacted] 45 cm = 130 cm^2, had glass walls with an external cathode of conducting paper. All statistical errors given below are standard deviations.

EXPERIMENT I

Experiment I is a refinement of an experiment previously described [2]. We registered (recorded) coincidences between four trays of counters (fig.1). Each tray consisted of three counters in parallel.

Fig.1 shows that at least two particles with sufficient energy to penetrate 19 cm of lead were needed in order to register a coincidence. The PS were absorbed in layers of lead 5 and 10 cm thick placed in position A between the trays of each telescope. We think that the production of PS in this lead is negligible because such a PS would have to contain at least one energetic particle going backwards. The local PS are produced in 29 g/cm^2 of carbon located above the arrangement as shown in fig 1. Our results are collected in table I. We see[redacted] that the atmospheric PS are not appreciably absorbed by the additional layers of lead, while the [redacted] local production is strongly absorbed in 5 cm of lead. These results are in agreement with those of the preceeding experiment [2]. We use in the present experiment carbon as producing material because the atomic weight of carbon is close to the mean atomic weight of the air. The similarity of the results of this experiment and of the preceding one where we used gasoline instead of carbon justifies the indiscriminate use of both materials in our experiments.

[redacted]

EXPERIMENT II

The purpose of this experiment is to repeat experiment I under different geometrical conditions: we wanted to study the absorption of local PS with an angular aperture sensibly smaller .

The PS were selected by three trays of three counters each (fig.2). The two outer counters in each tray were connected in parallel. We registered sixfold coincidences . For a coincidence to be registered there [redacted] to be [redacted] at least two particles able to penetrate [redacted] 10 cm of lead. The local PS were produced in carbon. In the cavities A and B we placed different thicknesses of lead absorber . Our results are collected in table II.

The high background counting rate without absorber is due to the fact that eletrons showers are still registered. From 2,5 cm to 10 cm of lead the background rate shows only a slight variation. This is due to a small absorption of the atmospheric PS. The locally produced PS are however strongly absorbed, as in experiment I.

EXPERIMENT III

In experiment III the PS are selected by two vertical telescopes, and variable thicknesses of lead are placed above a counter E located between the telescopes (fig 3). We measure in this way the penetrating power of a particle of the shower. Each tray of the telescopes consisted of three counters in parallel. Between the trays of each telescope was a permanent layer of 10 cm of lead. We registered both the coincidences among the four trays of the telescopes and the fivefold coincidences among these four trays and counter E.

In a preliminary measurement, without absorber above counter E we added 5 cm of lead to the screening of the telescopes, and the fourfold coincidence rate of the background decreased sensibly as shown in table III. This suggests that with only the permanent screening of lead some eletrons showers were still registered. When we further increased the lead screening, the background rate did not changed appreciably. This shows that no more eletron showers are registered with 15 cm of lead and confirms that the absorption of the atmospheric PS is weak. Repeating the same measurements with a producing material (38 g/cm^2 of gasoline) we observed that the locally produced PS registered by the two telescopes are strongly absorbed (table III). This is in agreement with the results of experiments I and II.

Afterwards, with a permanent screening of the telescopes of 15 cm of lead) and with 67 g/cm^2 of gasoline as producing material, we placed various thicknesses of lead above counter E. The fivefold coincidence rates with different thicknesses of lead are shown in table IV.

4) The absorber covers only (the) counter E so that it cannot change the rate of fourfold coincidences (rate) due to either background or local production of P.S. neither of the background nor of the local production. The PS produced in this absorber cannot be recorded (registered) due to its unfavourable position. These facts are confirmed by our measurements (table IV). This allowed us to collect all of the results of the fourfold coincidences without as well as with the producer. Table IV does not show any absorption of the fivefold coincidences without producer in agreement with experiments I and II. This allowed us to collect also all of the coincidences due to atmospheric PS. Taking into account that the fivefold coincidences are not statistically independent from the fourfold coincidences, we normalized all our data of fivefold coincidences to the common fourfold coincidence rate and accordingly reduced the statistical errors of the fivefold rates. Applying the method of least squares to the normalized fivefold coincidence rate, under the hypothesis that the absorption follows an exponential law, we found $e^{-1/L} = 0{,}982 \pm 0{,}010$ where L is the absorption length in cm of lead. The most probable value of L is 56 cm of lead (640 g/cm^2).

We investigated whether or not counter E was struck by photons resulting from the decay of the neutral mesons of the PS which constitute about half of the number of charged mesons (3). As the thickness of the wall of counter E measured in radiation lengths is $\ll 1$, this counter has a very low efficiency for the registration of photons. When covered with 1 cm of lead its efficiency will approach unity, in our range of energies. We thus expect the difference between the fivefold coincidence rate with and without 1 cm of lead to yield the frequency of these photons. Table 4 shows that this frequency is low. We believe that this happens because the angular dispersion of the two photons into which the neutral mesons decay is so large that only a few of them strike counter E. This sets an upper limit of roughly 1 Bev to the mean energy of the mesons which go in the direction of counter E, if we assume the number of photons to be about equal to the number of charged mesons [3].

Discussion

In our experiments the absorption of atmospheric PS is weak. The atmospheric PS must be produced in a mass of air at least of the order of the mass of producing material used in our experiments because the counting rates are of the same order. By geometrical considerations, we see that the center of this mass of air must be tens of meters above our arrangement. The largest part of the (registered) recorded atmospheric PS should consist of groups of particles having a very small angular dispersion and in consequence large energy, and should consist mainly of mu-mesons resulting from the decay of pi-mesons. For these reasons these particles should not disappear appreciably by ionization nor suffer nuclear interactions. It is interesting to notice that the predominating factor in the selection of the atmospheric PS is the small angular divergence rather than the thickness of lead used in our experiments so that the (registered) recorded particles of the atmospheric PS selected by our arrangement have an energy much larger than the minimum energy necessary to cross the lead shielding.

The results of experiments I,II and the absorption of the fourfold coincidences in experiment III,indicate that in the conditions of these experiments the absorption of the locally produced PS is strong,even if we take into account the fact that to absorb a PS it is sufficient to absorb in only one of the telescopes.The absorption of the particles which strike counter E in the locally produced PS (experiment III) is however weak.Because of this fact and because the cross section for nuclear absorption would have to be larger than the geometrical cross-section we do not believe that the contribution of nuclear interactions to the observed absorption of the fourfold coincidences due to the local PS is important.Thus the principal contribution to the absorption of the PS comes from particles stopped in the lead absorber after having lost their energy by ionization.Our experimental results are thus that the main part of the particles have an energy just above the minimum energy required to cross the lead screening.We believe that the local PS are not selected by the requirement of a particularly small divergence but by the thickness of the lead screening,which means that the minimum energy of the registered particles of the local PS should be just the energy necessary to penetrate this screening.As the spectral distribution of these particles is believed to fall off rapidly with increasing energy,the local PS would be easily absorbed.

It is very important to know the criterion by which the PS are selected by a given arrangement. Indeed,the PS are really "penetrating",i.e. their frequency does not depend within large limits on the thickness of the lead screening,only if they are selected by a special requirement such as their small angular divergence.This is why showers resulting from high energy nuclear explosions (high energy stars) discovered in the atmospheric PS may be called " penetrating". The registered local PS, though of the same nature as the registered atmospheric PS are not really " penetrating " in the sense given above , for reasons we have already discussed, but they are of course penetrating in the sense that some of their particles are able to cross large thicknesses of lead.

The small absorption of the local production (locally produced PS) in the absorber placed above counter E shows that the largest part of the particles of the PS wich strike this counter have an energy larger than that necessary to penetrate any of the absorbers . This fact indicates that the particles in the center of the PS (which have the direction of the primary particle) of the local PS have in the mean a larger energy than the lateral particles . This is easely understood by the laws of conservation of momentum. If ionization does not contribute to the observed absorption, the absorption length observed by us will be due to nuclear absorption and will be $\gtrsim$ 400 g/cm^2 . There is a correction due to the fact that counter E is sometimes struck simultaneously by more than one particle. Taking into account this correction and the statistical errors of the mesurements, we are still able to state that the nuclear absorption length cannot be shorter than 350 g/cm^2 . However because of the possible contribution of ionization and because of the statistical errors , we cannot give an upper limit to the nuclear absorption length.

Notice that since counter E was not struck by photons, we are measuring the absorption length for charged particles. The measure-

This is not correct. Mesons are greatly predominant among particles of minimum ionization. This is true not because there are more mesons than protons, but because protons have ionization appreciably higher than minimum up to energies much greater than mesons

ments with photographic emulsions (4) on PS of these energies indicate that at least 80% of the charged particles are pi-mesons, while the protons which constitute the remainder could not change our results appreciably, because their absorption length in lead is of the order of 300 g/cm^2. The distance from the producer to counter E is too small to allow the decay of the pi-mesons initially produced. We conclude that the cross-section for nuclear absorption of charged pi-mesons in lead in our range of energies is less than half the geometrical cross-section. This conclusion is in agreement with the result of other workers (5 - 10).

However our results do not allow us to make a definite statement on the value of the nuclear interaction length of the pi-mesons. Our arrangement is not sensitive to small-angle scattering with a small energy transfer to the lead nucleus. But it is believed that nuclear interactions should produce on the average rather large angle scattering and these were shown by Brown and McKay (5) to be 4 or 5 times less frequent than catastrophic interactions. Besides our arrangement has a reasonable efficiency for detecting large angle scattering. Another fact which could mask a possible nuclear interaction is the production by the pi-meson of penetrating secondaries in lead. It is rather difficult to meet this argument but we may remember that the energy of the particles striking counter E cannot exceed something like about 1 Bev. In order to reconcile our results with a geometrical cross-section (this corresponds to a mean range ~ 150 g/cm^2 in lead) for nuclear interaction, as found by the Bristol group (10), more than half of all interactions should result in the production of a PS able to strike counter E with high efficiency.We do not know if this can happen in our range of rather low energies.

AKNOWLEDGMENTS

We want to aknowledge our gratitude to the Comissão de Pesquisas Cientificas da Universidade de São Paulo and to its president,Prof. Souza Campos,for having supported our experiments in Campos do Jordão financially.We are grateful to Mr. Hans W. Hering for his hospitality.

São Paulo, October 4,1950

REFERENCES

(1) - ~~Sch~~ Ciccini, Meyer, Schwachheim and Wataghin

~~Communication de la Association Fisica~~
Comm.Ass.Fis.Arg. 23 Mayo 1949

(2) - Meyer, Schwachheim, Wataghin and Wataghin

Phys.Rev 75,908,1949

(3) - Carlson, Hooper and King

Phil.Mag. 41 ,701,1950

~~(4)~~ - Camerini, Fowler, Lock and Muirhead

Phil.Mag. 41 ,413,1950

4 (5) - W.W.Brown and A.S. ~~MacKay~~ McKay

Phys.Rev 77,342,1950

5 (6) - Butler, Rosser and Barker

Proc.Phys.Soc 63,145,1950

6 (7) - J.B.Harding and D.H.Perkins

Nature 164,285,1949

7 (8) - W.B.Fretter

Phys.Rev. 76,511,1949

8 (9) - Lovati, Mura, Salvini and Tagliaferri

Phys. Rev. 77,284,1950

9 (10)- O.Piccioni

Phys. Rev 77,6,1950

(10)

T A B L E I

Experiment I

Hourly rate of fourfold coincidences

Lead thickness in position A	Background (Atmospheric PS)	With carbon	Production in carbon
0 cm	1,79 ± 0,16	2,21 ± 0,15	+0,42 ± 0,22
5 cm	1,70 ± 0,13	1,53 ± 0,13	-0,17 ± 0,18
10 cm	1,39 ± 0,10	1,50 ± 0,10	+0,11 ± 0,14

TABLE II

Experiment II

Hourly rate of sixfold coincidences

Thickness of lead absorbers	Background (Atmospheric PS)	With carbon	Production in carbon (local PS)
0 cm	1,106 ± 0,069	1,455 ± 0,082	∼ 0,7
2,5 cm	0,656 ± 0,056	1,000 ± 0,077	0,344 ± 0,095
5 cm	0,562 ± 0,037	0,728 ± 0,037	0,166 ± 0,052
10 cm	0,443 ± 0,043	-	-

T A B L E   III

First part of experiment III

Hourly rates of coincidences

Lead thickness		0 cm		5 cm		10 cm	
Background (atmospheric P S)	fourfold rate	1,493	0,083	0,853	0,031	0,978	0,070
	fivefold rate	0,930	0,066	0,518	0,024	0,643	0,057
With gasoline	fourfold rate	2,009	0,106	1,175	0,056	1,084	0,090
	fivefold rate	1,181	0,082	0,672	0,042	0,693	0,071
Production in gasoline (local PS)	fourfold rate	0,8		0,322	0,064	0,106	0,114
	fivefold rate	0,6		0,154	0,049	0,050	0,091

TABLE IV

Second part of experiment III
Hourly rates of coincidences

Lead thickness above counter E	Background fourfold coincidences	Background fivefold coincidences	With gasoline fourfold coincidences	With gasoline fivefold coincidences
0 cm	0,834±0,051	0,518±0,026*	1,301±0,074	0,730±0,034**
5 cm	0,805±0,058	0,548±0,029*	1,195±0,069	0,751±0,034**
15 cm	0,906±0,074	0,496±0,034*	1,234±0,073	0,669±0,036**
20 cm	0,911±0,080	0,499±0,029*	1,186±0,064	0,679±0,030**
Average rate***	0,853±0,031	0,518±0,024	1,226±0,035	-
1 cm	0,876±0,081	0,539±0,038*	1,198±0,080	0,706±0,040**

* and ** - These statistical errors can be used only when comparing measurements in the same series.

*** - The measurements with 1 cm were not included when computing the average.