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INTRODUCTION

The present work was done in order to study some of the problems relative to penetrating showers in cosmic radiation. The experiments were performed at an altitude of I750 m. in Campos do Jordão from August to December I948. We investigated the following problems. I. The altitude dependence of the frequency of meson showers. We studied this dependence for showers produced locally in water, as well as for showers produced locally in the atmosphere and in the lead shield of the counter arrangement.

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II. The determination of the absorption coefficient of the penetrating showers-producing radiation in water.

III. The East-West asymmetry of the radiation responsible for penetrating showers. IV. Besides, a complementary experiment to our work on the nature of the mesons produced in penetrating showers (I) has been performed.

In the following text we shall use the abbreviations PS. for penetrating showers (meson showers) and PSPR. for the penetrating shower-producing radiation.

DETERMINATION OF THE MEAN RANGE OF PSPR IN THE ATMOSPHERE.

For this purpose we used in Campos de Jordão (atmospheric depth ~844 gr/cm^2 latitude 23° S.) an experimental arrangement identical to that used prevously in S.Pauolo (I) (atm.depth ~950 gr/cm^2), and worked in both cases under a very thin roof. The study of the variation of the frequency of PS with the altitude was initiated by Sala and Wataghin (~~4,5,6~~ 2,3,4), and later continued by G.W. Assuming an exponential law of variation in function of the atmosphere pressure (~~8~~ 4), ~~one can deduce from their measurements following values of the mean range : 85 ± 30; II2 ± I0; 93 ± 5.~~ G.W. Ty estimated ~~indicated~~ to be the mean range ~100 g/cm Tinlot (~~7,8~~ 5,6), working at a geomagnetic latitude ~~of~~

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① 53°, confirmed that the dependence of the registered frequency on the barometric pressure is ~~approximately~~ an exponential one and found a mean range of $\ell \simeq 118 \pm 2$. In our present measurements we find a mean range of 102 ± 9 gr/cm^2. It seems remarcable that the barometer-effect of the total radiation (Myssovsky ~~&~~ and Tuvim, 1926), of extensive energetic showers (Auger, Daudin, Cosy~~i~~ns) and of local penetrating showers (Janossy, ~~&~~ Rochester) gives an absorption coefficient of the same order of magnitude (e.g. ~~Dadin~~ for total radiation at a latitude of 60°: $\ell \sim 190$ gr/cm^2; for extensive energetic showers: $\ell \sim 100$ gr/cm^2, for PS: $\ell \sim 116 \pm 27$ gr/cm^2) The last results of Janossy and Rochester can be understood immediately by the comparison with the measurements of frequency of PS at various altitudes. In both cases the frequency is obtained either by the meteorologic fluctuation at a fixed altitude or by working with the same apparatus at different altitudes. A possible interpretation of approximate validity of the exponential law for these ~~se~~ local PS, as due to the variation with atmospheric depth of the number of energetic nucleons, which are locally absorbed and produced in the nuclear collisions, was recently discussed by one of us. (9)

Myssovsky & Tuvim
Zs. f. Phys.
v. 39, p. 146, 1926

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At present state of our knowledge we can assume that in PS take part not only π-mesons and eventually other mesons, but also fast nucleons. Indeed, e.g. neutral PSPR, observed by Janossy and Rochester and by Regener and Rossi, is probably due to fast neutrons. We should expect that not only the energetic nucleons but also some of the~~se~~ short lived mesons are capable of generating new PS [whereas nucleons and heavy mesons of low energy produce stars]. Thus the mechanism of production of local PS and of extensive PS must be one of cascades of showers of mesons and nucleons. From our present experiments we are led to conclude that the mean free path for fast nucleons is of the order of 55 gr/cm^2 so that few primary protons reach

Mais prudencia ?

sea-level. From our recent observations on short-lived mesons ( ) follows that their mean range is ~ 300 gr/cm². One must also take into account that the average spectral distribution of energetic nucleons can vary with the altitude and that the cross-section for production of PS of a definite type is certainly dependent on the energy of the nucleons. ~~From this point of view~~ All these facts make us think that the exponential law of variation of PSPR can have only an approximate validity and the measured mean range is due to a superposition of effects of absorption and production of nucleons and mesons, which are difficult to analyse, Some contribution to such an analysis is attempted in this paper. First we ought to consider the effect of the wellknown " Gross-transformation" in order to establish a relation between the registered variation of the frequency of PS with atmospheric depth and the ~~supposed exponental~~ law of absorption for a parallel beam ~~for the unidirectional flow~~ of a monoenergetic PSPR. Then we shall take into account the effect of the local variation of the density of air.

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In many experiments the arrangement of counters in the PS detectors can be considered as equally sensitive to all directions of incidence of the PSPR [isotropic detectors]. In these cases we ought to consider the so called "integral intensity" of the PSPR and, assuming an exponential law: $\underline{I}(x) = \underline{I}_0 \exp(-x/l)$ for the unidirectional ~~flow~~ beam of monoenergetic nucleons, we have at the atmospheric depth x gr/cm^2 :

integrated

(1) $$\mathcal{J}(x) = \iint \underline{I}(x/\cos\vartheta)\,d\omega = 2\pi \underline{I}_0 \int_0^{\pi/2} \exp(-x/l\cos\vartheta)\operatorname{sen}\vartheta\,d\vartheta = 2\pi \underline{I}_0 \exp\left(-\frac{x}{l}\right) A(x)$$

where $\underline{I}(x/\cos\vartheta)\,d\omega$ is the number of nucleons incident within the solid angle $d\omega$, in 1 sec., on 1 cm^2. perpendicular to the direction of incidence; ϑ is the zenital angle; l is the mean range of the PSPR and $A(x)$ is (10):

(1') $$A(x) = 1 + \frac{x}{l} \times \exp\left(\frac{x}{l}\right) \times Ei\left(-\frac{x}{l}\right)$$

Myssowsky Tuwim, l.c.

In a similar way, we must consider, in the case of a detector having Counters arranged in a horizontal plane, the so called "integral flux" :

→ (2) $$J_1(x) = \iint I(x/\cos\vartheta)\cos\vartheta\, d\vartheta = 2\pi I_0 \exp(-x/\ell)\, B(x)$$

where

Corretto. → (2') $$B(x) = \frac{1}{2}\left[1 - \frac{x}{\ell} - \frac{x^2}{\ell^2} e^{x/\ell} Ei(-x/\ell)\right]$$

For $\frac{x}{\ell} \gtrsim 10$ one has approximately : $B(x) \cong \frac{\ell}{x}\left(1 - \frac{3\ell}{x}\right)$ —

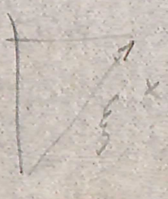
Assuming that the conditions of the validity of the Gross-transformation are satisfied for PSPR (e.g. assuming the isotropy of the incident primary radiation at the top of the atmosphere and supposing that secondary particles (nucleons and mesons) of the PSPR move nearly in the same direction of the primaries), we can apply the Gross-trasnformation to the observed nearly exponential law of variation of the frequency of PS with the atmospheric pressure, and conclude that the absorption curve for a parallel beam of rays is also nearly an exponential one.

corretto → (e. g. , putting $J(x) \sim e^{-x/\ell}$ one has: $I(\xi) \sim (1 + \xi/\ell)\, e^{-\xi/\ell}$

" → whereas assuming $J(x) \sim \frac{1}{x} e^{-x/\ell}$ one obtains : $I(\xi) \sim e^{-\xi/\ell}\left[1 + \frac{2\ell}{\xi}\right]$)

The interpretation of the observed variation of the frequency $f(x)$ of PS with the atmospheric depth x requires the knowledge of the ~~local~~ origin of the PS: we must distinguish the PS produced in the air ~~near~~ surrounding the detector from the PS originated in the lead shielding of the counters . ~~In fact~~ Indeed ....

$e^{-x}\left(1 + \frac{2}{x}\right)$



$\xi = \frac{x}{\cos\gamma}$

Indeed in the first case the registered frequency of the PS is obviously proportional to the local density of the surrounding air and to the local **intensity** of the PSPR , whereas the frequency of the PS produced in lead shield or in the layers of other materials located in a fixed position near the detector is independent of the air density. (Obviously , for every kind of the incident PSPR and in every point the frequency of the produced PS is proportional to the concentration of the nuclei which suffer collisions with the incident particles). The consideration of the density of air for showers produced in air obliges to introduce an important correction in the deduction of the value of the mean range and requires supplementary experiments in order to determine the proportion of air showers in the total number of the registered PS.

Thus even assuming an exponential absorption for parallel beams of PSPR (nucleons) in air , with a mean range nearly independent from the energy of the incident particles of the PSPR , and neglecting the eventual contribution of the heavy mesons , we must take into account separately the PS produced in the air and those generated in the aparatus : the ratio of the frequencies $f(x_1)$ and $f(x_2)$ registered at two altitudes x_1 and x_2 by the same detector , in the case of air showers is : $\frac{f(x_1)}{f(x_2)} = \frac{x_1 A(x_1)}{x_2 A(x_2)} \exp\left(\frac{x_2-x_1}{\ell}\right)$, whereas for showers produced in the aparatus the factor (x_1/x_2) must be omited . Similar arguments are valid also wnen the formula (2) is used . In order to illustrate the uncertainties due to the lack of knowledge of the porcentage of air showers in the total number of registered PS , we apply the preceding considerations to the measurements of Tinlot and find , assuming that 100% of the registered PS are produced in air , the value : $l \sim 113$ gr/cm^2 instead of 118 gr/ cm found interpreting his curve by a simple exponential law ; and assuming that all showers were produced in lead we obtain : $l \sim 139$ gr/cm^2. Similar uncertainty concerns also some of our results and those of other authors when e.g. they measure the frequency of stars, or of slow mesons of certain type, or neutrons, in the neighbourhood of heavy materials .

Even more difficult is the comparison of data obtained by different arrangements of counters and made in different magnetic latitudes . Therefore it seems rather surprising that all measurements of the mean range of PSPR give results ~~which make us estimate this meanrange~~ in accord with the following rough estimation: $90 \lesssim l \lesssim 140$.

In order to avoid at least the uncertainty due to the air showers we studied the variation with altitude of the frequency of PS produced locally in the same amount of water using as detector the arrangement of two " telescopes " protected by lead indicated in the Fig. 1 ; We observed the following increase of the rate of fourfold coincidenc due to 57 gr./ cm^2 of water respectively in S. Paulo and in Campos de Jordao : $f_1/f_2 = \cancel{2.80 \pm}\ 2,78 \pm 0,51$.

Thus applying ~~(1)~~ the above considerations, we obtained a mean range : (114 ± 20) gr/cm^2

Unfortunately the obtained determination is not sufficiently accurate to permit conclusions on the partecipation of air showers in PS registered by our detector

II. Absorption of PSPR in water.

The absorption of PSPR and the production of PS in various material can be studied conveniently on the basis of the so called transition effect. The first observations of the transition effect of PSPR are due to Janossy and Rochester. After some measurements of this effect in San Paolo (1), we performed, in Campos de Jordao, other researches, described below, on the transition effect in water. We used a PS detector (fig.1) consisting of two "telescopes" of Geiger counters completely shielded by lead, so that a particle, in order to be registered by a telescope, should produce a coincidence trough at least I8,5 cm.Pb. The counter trays had an area of 600 cm.^{2} each, and were connected in fourfold coincidences. The resolving time of the circuit was of 1 microsecond and the few accidental coincidences were taken into account in our results. The water was contained in vessels of light materials having walls of thickness of ~ 2 gr/cm^2(**). We increased the thickness of water till 125 cm. Our results are shown in table I and fig.2.

aqui segue: [como na pag. 6ª e seguintes do manuscrito)
Table I
fig. 1 and 2
etc.
e pag. 7 do manuscrito
até o fim da pag. 7
sem alterações.

depois vai a pag. 9 nova!

→ XXXX

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(1) Meyer Schachter A. Wataghin Phys. Rev. 74, 841, 1948

(**) Calculei assim: peso de uma tina ~ 60kg
superficie total ≃ 30000 cm^2

depois da pag. 7 do manuscripto original → $\boxed{XXXX}$

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(substituting page 8 etc.of your manuscript)

DISCUSSION.

As is well known, in the case of a parallel beam of a monocromatic PSPR, incident ~~at~~ a right angle on an extended plate of thickness y the transition effect can be represented by the formula :

(4)
$$I(y) = I_0 + I_1 \left[1 - e^{-by} \right] \qquad (4)$$

where $I(y)$ is the frequency of PS registered below the plate and where b is the absorption coefficient of PSPR (See e.g.Janossy Cosmic Rays page). Here we suppose negligible the absorption of particles of PS in the plate and assume that the registration is made by a convenient flat detector. If (as we suppose) the incident nucleon of PSPR produces, during the collision giving rise to PS, some secondary fast nucleons capable of generating new PS in the material of the plate, then the significance of the coefficient b depends also on the nature of the detector: in the case of an "integral detector" which registers all the PS, one would obtain for b the value corresponding to the combined effect of absorption and production of PS, whereas in the case of a detector of the type we used most of the showers produced in the plate by secondary nucleons would not be registreted separately, because they are produced simultaneously to the primary shower. In this case the value of b would give us the mean free path for a high energy collision of a particle of PSPR (nucleon).

Another simple transition effect permitting the determination of b of a monocromatic PSPR we encounter ~~one has~~ in the case of an infinitely extended horizontal plate of variable thickness y and of an isotropic detector. As is well known (*) the transition curve in this case is given by the formula :

(5)
$$\mathcal{I}(y) = \mathcal{I}_0 + \mathcal{I}_1 \left[1 - f(by) \right] \qquad (5)$$

where $f(by) = e^{-by} + by\,Ei(-by)$ and $-Ei(-\xi) = \int_{\xi}^{\infty} \frac{e^{-u}}{u}\,du$

is the exponential integral. The validity of (5) in our case is ~~que~~ questionable not only because of finite extension of our plates, but also because we ignore the law of wariation of frequency of

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(*) L.V. King Phil. Mag. V. XXIII, p.294, 1912 registration of PS by our detector in function of the distance(and of the location)of the point of production of PS from the detector. The validity of (5) is based on the assumption of the inverse square law for this dependance, and we know only that in average this frequency decreases when the distance is increased. Taking into account the finite extension of the "plates", in our case, and using some approximation in the calculus of $J(y)$ we find that the expected dependance of J from y ~~must be~~ is intermediate between those given by the formulae (4) and (5).(The uncertainty of the experimental data does not permit to distinguish between $\exp(-by)$ and $f(+by)$).

We need also consider an average value for $b = b(E)$ as a function of the energy E and eventually of the nature of the particles of PSPR (because this radiation can be composed of different types of particles e.g. of nucleons and of some kind of mesons).

Applying these considerations, we find, by trial, the values of the parameters $I_0 I_1$ b which fit the curve~~s~~ of the experiment~~s~~ A. ~~and B.~~ The mean range $l = b^{-1}$ resulting from the experiment A is : $40 \lessapprox l \lessapprox 70$ (gr/cm.^{2})

In the experiment B we note the importance of the geometrical factor : the increased average distance of the centers of production of PS from the detector gives rise to the reduction of the rate of production by a factor ~ 2.

In the experiment C, we think, one obtains a reasonable approximation by applying the ~~formulae~~ exponential law ([illegible]) valid for parallel beams and thus we deduce the mean range l by the formula~~e~~ :

$$\frac{A_{12} - A_2}{A_1 - A_0} = \exp(-y/l)$$

where y is the water thickness in the upper tank. Series I yields a mean range for the PSPR of 55± 27 gr/cm. and series 2 a mean rang of 53 ± 25 gr.cm. The average value resulting from series I and 2 is 54 ± I9 gr.cm.

We consider the results of the experiment C as the most significant for the purpose of the determination of the value of the mean free path b^{-1} of the PSPR. Comparing experiments A, B, and C with our recent results on PS (*) , where the average range in Pb of the majority of ionizing particles constituting local PS appears to be $>$ 210 gr/cm² and probably $<$ 320 gr/cm², we conclude that the absorption of these particles (constituting PS) in water in our experiments did not ~~alter~~ influence essentially our measurements and could not influence the validity of our arguments . Indeed experiments [our own ( ) and those of other authors] seem to indicate that the stopping process of particles of PS ~~xxx~~ is of the type characteristic of a particle which looses its energy by ionisation but at the end of its range suffers a catactrophic absorption (producing stars or suffering disintegration).

(sobre π-mesons)

We think also that one can find a support of our interpretation of the experiments A, B, C as giving the mean free path of PSPR (or the average cross- section for the collision of incident nucleons with nuclei of H_2O giving rise to PS) in the beautiful experiments carried in a V-2 rocket by Van Allen and Tatel (**) . The counting rate of an unshielded Geiger counter shows in their measurements a maximum at an atmoshperic depth of 58 gr/ cm², and a rapid increase of intensity is already noticeable at a depth between 12 and 26 gr/ cm² . Remembering that at these depths the primary radiation is distributed nearly isotropically and applying thus the formula(†) we find : $b^{-1} \sim 50$ gr/ cm² .

aquella con: $[1-f(\xi)] = 1-e^{-\xi}-\xi Ei(-\xi)$

(**) Phys. Rev. 73 p. 245, Feb. 1948.

100 b
50
$H_2O = 50$
C = 100
Fe = 140
Pb = 300

In conclusion there is a definite desagreement between the value of $b \sim 55$ gr/ cm^2 and the value of $l \sim 120$ gr/ cm^2, the last one obtained from the variation with altitude of the rate of PS. This desagreement indicates , in our opinion , that there is a process of production of PSPR (e. g. of secondary energetic nucleons) which ~~is~~ interfers with the absorption of this radiation . Thus the measurement of the mean range l of PSPR in air gives us the value of an apparent absorption coefficient l^{-1} which is the difference between the real absorption coefficient b and the coefficient b^* of the production of a secondary PSPR (*) . With the values $b \cong 55$ gr/ cm^2 and $l \cong 120$ gr/cm^2 we find : $b^* \cong 100$ gr/ cm^2.

citare * my letter to the Editor 15 Ottob

III . EAST - West ASYMMETRY OF THE PSPR.

In order to study the East- West asymmetry of PSPR we performed a series of measurements using the arrangement indicated in Fig. 3 . The water tank was located altenatively ~~first~~ to the East and ~~then~~ to the West of the detector . The particles of PS produced in water and registered by the detector had , obviously , a direction inclined relative to the vertical . It seems plausible to assume that the PSPR responsible for these inclined showers has also direction in most cases (but not allways) coming from the East or from the West respectively . We performed two different experiments I and II . The asymmetry of the position of the tank was greater in the experiment II . The counter- arrangement in both experiments was the same as the one described in section II. ~~XXXXXXXXX~~ Our results are collected in the Table IV :

TABLE IV.

Neither of the experiments showed an asymmetry , within the experimental errors . However already in the experiment I an asymmetry $\lesssim$ 25% would be masked by a statistical fluctuation $\sim$ standard deviation . We believe that many causes in our experiment could contribute to mask the effect of a possible East West asymmetry of the PSPR . However it seems possible that at higher altitudes this asymmetry may become appreciable .

IV. Complementary Experiment on the penetrating power of PS.

In a previous work we discussed our experiments on the nature of the particles constituting the PS. We were led to ~~the~~ conclude that the produced mesons should be π- mesons rather than μ- mesons . An essential point in our argument was the fact that when the lead protection of the counters was increased by addition of 10 cm Pb the rate of fourfold coincidences remained inaltered . The interpretation we gave was that the showers produced in the atmosphere were not absorbed by the additional ~~xx~~ layer of lead . The possibility of an alternative interpretation , based on the existence of PS produced directly in the lead-shield would not alter our conclusions about π- mesons , but could trow some doubt about the penetrating power of the particles of atmospheric PS. Therefore an auxiliary experiment was made in order to study the number and the pentrating power of ionizing particles of PS, by means of a detector in which the registration of a PS produced in the lead shield should be very improbable . We used the arrangement indicated in Fig ; and registrated 3-fold and 4- fold coicidences due to PS generated in air and in H O. Each counter in the trays 1234 had an area of 130 cm . The counter 5 had an area of 240 cm . The trays 1and 4 were connected to the same line of the coincidence circuit . An additional lead shield of 10 cm Pb was some times introduced . The rate of 3- fold coicidences without additional lead was : 4.96+ 0.23 and with this shield ~~s~~ 5.03+0.16

This result supports our argument about the penetrating power of the particles of PS .

We measured also the rate of 4-fold and 3-fold coicidences with and without a layer of 57 gr/cm of H O (as producing layer See Fig.) and obtained the following results:

TABLE V

water	f_3	f_4
0 cm	5.03+ 0.16	1.70+0.09
57 CM	5.82+ 0.18	2.44+0.12

As is well known the ratio $\frac{f_4}{f_3} = \frac{2.44-1.70}{5.82-5.03} \approx 1-e^{-\bar{\delta} S}$, between the rates of PS produced in H O gives us an approximate measure of the average density $\bar{\delta}$ of penetrating ionizing particles falling on the detector . This density $\bar{\delta}$ results of the order of : 10^{-2} cm $^{-2}$.

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Table from the paper
L.V. King Phil. Mag.
Vol.XXIIIiSixth Series
January-June I9I2-page 244

Table

$$f(x) = e^{-x} + x\,Ei(-x)$$

x	e^{-x}	$f(x)$
0	1.0000	1.0000
0001	.9999	.9990
001	.9990	.9927
01	.990050	.9497
02	.980199	.9131
03	.970446	.8817
04	.960789	.8535
005	.951229	.8278
06	.941765	.8040
07	.932394	.7819
08	.923116	.7610
09	.913931	.7412
.1	.904837	.7225
.2	.818731	.5742
.3	.740818	.4691
.4	.670320	.3894
.5	.606531	.3266
.6	.548812	.2762
.7	.496585	.2349
.8	.449329	.2009
.9	.406570	.1724
1.0	.367879	.1485
1.1	.332871	.1283
1.2	.301194	.1111
1.3	.272532	.0964
1.4	.246597	.0839
1.5	.223130	.0731
1.6	.201897	.0638
1.7	.182684	.0558
1.8	.165299	.0488
1.9	.149569	.0428
2.0	.135335	.0375
3.0	.049787	.0106
4.0	.018316	.0032
5.0	.006738	.0010
6.0	.002479	.0003