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# On the Disintegration of Slow Mesons

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With the same experimental device used in a previous work for a direct determination of the mean life of slow mesons, we have performed some measurements designed to give indications about the disintegration process of the mesons stopped in an iron plate. In agreement with the theoretical predictions of Tomonaga and Araki we found that only about one-half of the ionizing particles that compose the hard component of the cosmic rays and that are absorbed in an iron plate, undergo, in effect, the disintegration process. From the same experimental results, one deduces that the mean range of the decay-electrons is about 2.5 cm of iron, with a probable precision of 20 percent.

## 1. INTRODUCTION

IN a previous paper[1] we reported a direct measurement of the value of the mean life $\tau$ of the disintegration process of the mesons stopped in an iron plate, with the following result:

$$\tau = 2.33\ \mu\text{sec.} \pm 6.5\ \text{percent.}$$

Later we decided to perform some measurements with the same experimental arrangement in order to find out what percentage of the particles forming the hard component of the cosmic rays and absorbed by a plate of a heavy substance (iron) actually undergo the disintegration process. From Tomonaga and Araki's[2] calculations it follows that the probability that a meson interacts with the nuclei of the substance penetrated depends not only upon the thickness of the substance and upon the energy of the meson, but also upon the sign of its charge. In fact, on account of the Coulombian repulsion, positive mesons would have such a small probability of being captured by the nucleus that this could be neglected in comparison with the probability of decay. On the contrary for negative mesons of low energy the probability of capture would be much greater than that of decay. Consequently, among the mesons absorbed in a heavy substance, only the positive mesons could practically disintegrate, each producing one electron and one neutrino.

Measurements designed to check these theoretical conclusions have already been taken by Rasetti[3] and, independently, by Auger, Maze, and Chaminade,[4] who measured, by a different technique, the delayed coincidence in several groups of counters. The results obtained by these authors are contradictory: Rasetti found in agreement with Tomonaga and Araki's calculations that only about one-half of the stopped mesons disintegrate. Auger and collaborators, on the contrary, found that all the mesons undergo the disintegration process; unfortunately we have only a short report on the work of these last authors, which does not contain exact and sufficient details about the experimental method.[5] Moreover, Rasetti implicitly assumes in his work that the differences between the proper delays introduced by the various branches of the registering device can be neglected, while the error which is thus introduced cannot be neglected *a priori*, especially for a registering set which does not have small time constants. As a matter of fact, in order to determine the ratio $\eta = M/A$ between the number $M$ of mesons which disintegrate and those $A$ which are stopped in the absorber, it is necessary to know the

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[1] M. Conversi and O. Piccioni, Nuovo Cimento **II**, 40 (1944); M. Conversi and O. Piccioni, Phys. Rev. **70**, 859 (1946).
[2] S. Tomonaga and G. Araki, Phys. Rev, **58**, 90 (1940).
[3] F. Rasetti, Phys. Rev. **60**, 198 (1941).
[4] Auger, Maze, and Chaminade, Comptes rendus **213**, 381 (1941).
[5] Unfortunately in recent years we received only a few scientific papers.

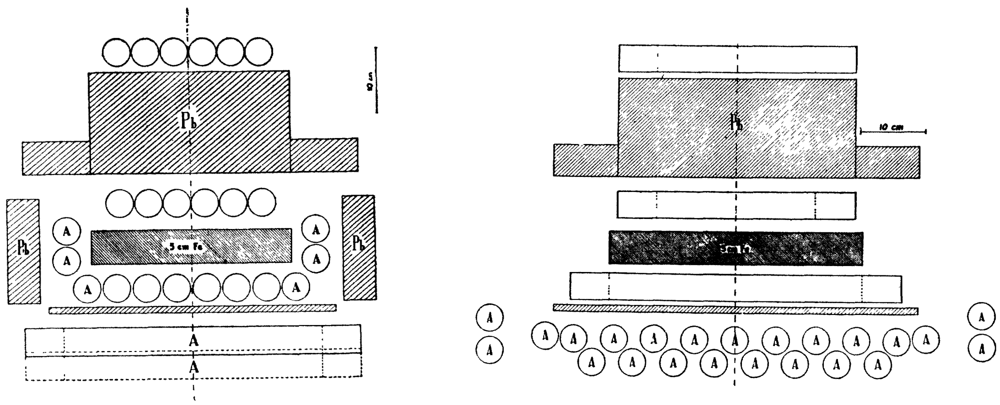

FIG. 1a and 1b. Vertical sections of the whole set of counters.

absolute delay, that is, the sum of the introduced delay and the algebraical difference between the proper delays of the branches of the registering set. In the present work, we have been able to evaluate the absolute delay (see Section 2) so that the error affecting the ratio depends essentially upon the statistical errors affecting $M$ and $A$. Our measurements, moreover, allow one to obtain an indication about the value of the mean range of the disintegration electrons in the iron.

For a complete description of the experimental arrangement used in this work, we refer to the earlier work on the direct measurement of the mean life of the meson.[1] Here we give only a general description of the counter system and the registering apparatus. The experiment was carried out in Rome, in a classroom of the R. Liceo Virgilio.

## 2. THE EXPERIMENTAL ARRANGEMENT—EVALUATION OF ABSOLUTE DELAY

Figure 1 shows, in a vertical section, the disposition of the counters, the lead screens, and the iron absorber. The geometry of our arrangement is indicated by Fig. 1. The 15-cm thick lead layer, interposed between the first and second group of counters, absorbs practically all the soft component and allows at the same time the use of a convenient energy interval of the differential spectrum of mesons.[6,7] In addition to the 15-cm Pb, we must take into account about 150 g/cm of Ca, corresponding to the three floors of the building over the experimental device. The third group of counters reveals the disintegration electrons, since their pulses are normally registered only if they are in delayed coincidence with those of the two first groups. The fourth group of counters, covering as well as possible the solid angle defined by the two first sets, is connected to the circuit of the quadruple coincidences; subtracting the number of the quadruple coincidences from that of the triple coincidences, thus we eliminate the random coincidences due to one or more particles of which at least one crosses the fourth group of counters.

With such a procedure the number of the registered random coincidences is strongly reduced.

The counters of the fourth group are marked in Fig. 1, with the letter $A$. The Pb plate 1-cm thick, placed immediately underneath the third group, is designed to stop the disintegration electrons which have crossed one of the counters of the same group: a triple coincidence not followed by a quadruple one corresponds to the delayed emission of an electron.

The other lead blocks are designed to protect the counters from the showers. For a complete description of the registering device see our former paper[1]; here we give only the disposition of the different parts (Fig. 2) and a short description of their operation.

The pulses, at the input of the two first branches, amplified through the two input stages, coincide in $CS$ (1–2), which like $CS$ (1–2–3) and

[6] Bruins, Proc. Roy. Soc. Amsterdam **17**, 672 (1939).
[7] Cocconi, Ricerca Scient. **11**, 58 (1940).

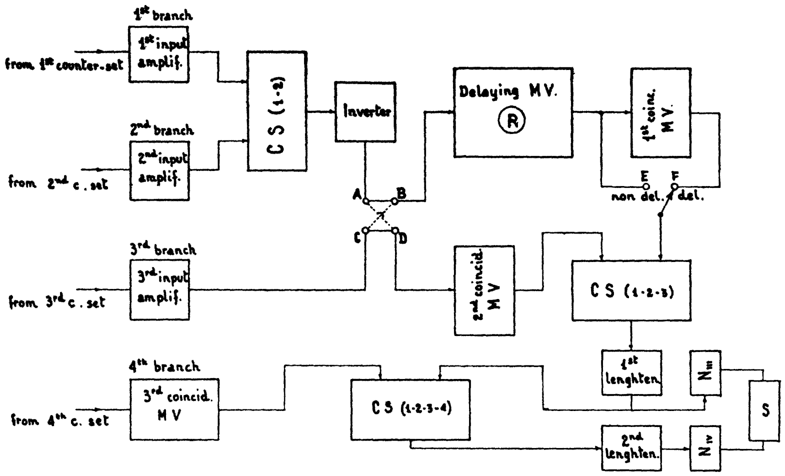


FIG. 2. Block diagram of registering set.

*CS* (1–2–3–4) is a system of double coincidences "in series."[8]

The positive coincidence pulse must be inverted before being sent through the connection *AB* to the delaying multivibrator. The latter, at the arrival of a negative pulse in *B*, produces a positive rectangular pulse, the duration of which is determined by the choice of certain elements of the circuit, forming together an interchangeable delaying group *R*.

The first coincidence multivibrator is sensitive only to negative pulses; it will work, then, only in the decreasing part, that is, at the end of the positive pulse of the delaying multivibrator and its pulse will be delayed by a time interval with respect to that of the double coincidence. One of the two tubes of *CS* (1–2–3) is permanently connected with the end of the second coincidence multivibrator. The other tube can be connected either with the end *E* of the delaying multivibrator (not delayed coincidences) or with the end *F* of the first coincidence multivibrator (delayed coincidences). In the second case, the coincidence occurs between the pulse $\theta_{12}$ of the first coincidence multivibrator and the pulse $\theta_3$ of the second coincidence multivibrator and $T=\theta_{12}+\theta_3$ is the double of the resolving power of the system *CS* (1–2–3). In order to decrease the proper delay of the fourth branch, the third coincidence multivibrator has been connected directly with the fourth group of counters; the time length $\theta_4$ of its pulse ($\sim 9$ $\mu$sec.) is, moreover, much greater than the time lengths $\theta_{12}$, $\theta_3$. The working conditions of the experimental device have been checked by means of the same methods applied in the experiments for direct measurement of the mean life of mesons.[1] Among them, let us consider in some detail the curve of the counting rate of the quadruple coincidences as a function of the introduced delay "for short delays" which in the present case, has a particular importance. In fact, from this curve it is possible to evaluate the absolute delay in the following way. Let us suppose that the same particle crosses simlutaneously the four groups of counters; it will cause (a) a double coincidence between the first and the second branch, which will produce a delayed pulse $\theta_{12}$ of the first coincidence multivibrator; (b) a pulse $\theta_3$ in the second coincidence multivibrator (third branch). Because of the fluctuations in the steepness of the counters-pulses both the pulses $\theta_{12}$, $\theta_3$ will not be produced after an exactly constant time interval evaluated from time zero (time when counters are crossed by the impinging particle).

Let us imagine that, for a certain delay $\theta$ of the delaying multivibrator, the most probable positions of the two pulses $\theta_{12}$, $\theta_3$ are that given in Fig. 3a. The time interval $\vartheta$ between the end of $\theta_3$ and the beginning of $\theta_{12}$ is the absolute delay, since two independent particles, one of which crosses the first two groups of counters and the other the third one, would cause a coincidence only if the second (coincidence) is delayed at least for a time interval $\vartheta$ with respect

[8] O. Piccioni, Nuovo Cimento 1, 56 (1943).

to the first one, while, on the other hand, the coincidence produced by a single particle would be registered at the limit for $\vartheta=0$. The above-mentioned fluctuations of the counter pulses will cause fluctuations also in the positions of pulses $\theta_{12}$, $\theta_3$, which will be distributed in time as indicated by the differential curves $f_{12}(t)$, $f_3(t+\vartheta)$ of Fig. 3b. It may be seen that $f_{12}$ is referred to the beginning of the pulse $\theta_{12}$ and $f_3$ to the end of $\theta_3$, and that both are wider than $\theta_{12}$ and $\theta_3$. Their shape has been drawn rather arbitrarily, but it is sufficient for our purpose to assume that they are symmetrical with respect to the maximum. Such an hypothesis cannot be considered strictly verified, especially for $f_{12}$ which is the result of the coincidences between the first and the second branch. But the error introduced can be neglected in the determination of the ratio $\eta$

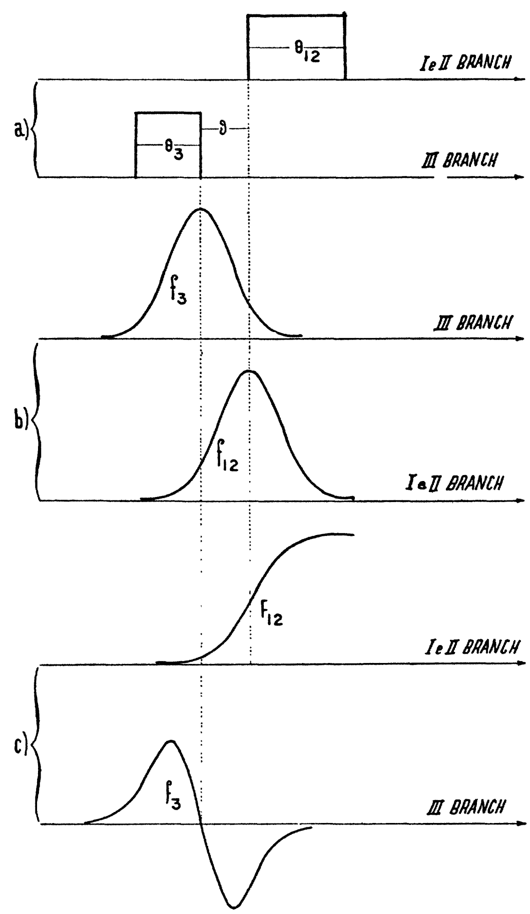


FIG. 3. Diagrams showing how the shape of IV ($\vartheta$) curve is obtained. $f_{12}$, $f_3$ are differential distribution curves of pulses $\theta_{12}$, $\theta_3$.

(see Section 3). Since, for greater delays, the threefold coincidence counting rate III would be affected by the decay electrons, we preferred to put in Fig. 4 the fourfold coincidences counting into IV, keeping in mind that on account of the great width $\theta_4$ of the third coincidence multivibrator, IV differ from III only by an efficiency factor independent of $\vartheta$. Then, omitting a small constant part, because of the random coincidences of two or more particles, and putting briefly:

$$F_{12}=\int_{t-T}^{t} f_{12}(t)dt \quad [T=\theta_{12}+\theta_3],$$

we can practically write:

$$IV(\vartheta)=\int_{-\infty}^{+\infty} F_{12}(t)f_3(t+\vartheta)dt.$$

Differentiating with respect to $\vartheta$, and integrating by parts successively and omitting the term $f_{12}(t-T)f_3(t+\vartheta)$ we obtain

$$\frac{d}{d\vartheta}IV(\vartheta)=\{F_{12}(t)f_3(t+\vartheta)\}_{-\infty}^{+\infty} - \int_{-\infty}^{+\infty} f_{12}(t)f_3(t+\vartheta)dt.$$

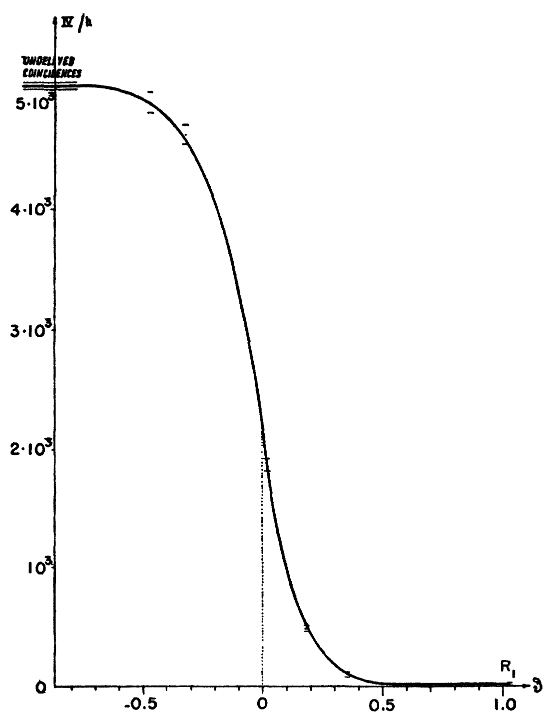


FIG. 4. Fourfold coincidence rates at small delay.

Since the first term on the right-hand side of this equation is obviously zero (Fig..3b and 3c), we obtain

$$\frac{d^2}{d\vartheta^2}IV(\vartheta) = -\int_{-\infty}^{+\infty} f_{12}(t)\cdot f_3'(t+\vartheta)dt,$$

where $f_3' = df_3/d\vartheta = df_3/dt$ is plotted in Fig. 3. This integral is obviously zero for $\vartheta = 0$, on account of the symmetry of $f_{12}$ and $f_3$. Thus the point of inflection of the curve IV ($\vartheta$) corresponds to $\vartheta = 0$ and the distance of this point from the point $R$, corresponding to the introduced delay, gives the value of the absolute delay. A certain inaccuracy in the value of $\vartheta$ is connected with the errors affecting the measurements of the introduced delays, also with the statistical errors affecting the experimental points of the various curves IV ($\vartheta$) and with the uncertainty of the determination of the point of inflection. This error however is certainly less than 0.2 $\mu$sec. as can be seen from Fig. 4. The delays corresponding to the points of the experimental curve of Fig. 4, as well as the pulse time-length of all multivibrators, were frequently checked during the experiment by means of the calibrating set described in our previous paper.

### 3. MEASUREMENTS, RESULTS, AND THEIR INTERPRETATION

Measurements of two types have been carried out alternatively in order to obtain the value of $\eta$.[9]

(a) Measurements of the delayed coincidences III and IV with absolute delay 1.025 $\mu$sec., have been taken with and without a 0.6-cm iron absorber.

(b) The undelayed coincidences between the double coincidences $D_{12}$ (1st and 2nd group of counters) and the triple coincidences $T_{124}$ (1st, 2nd, and 4th group) were measured alternatively with and without a 5-cm iron absorber.

The iron 0.6 cm thick, used in the measurements of the 1st type, was chosen in order to make them independent of the mean range of the disintegration electrons in the iron, the value of which is not known with sufficient accuracy but is certainly much greater than 0.6 cm.

From the measurements of the 1st type, the counting rate $m$ of the mesons, stopped in the iron-plate and producing disintegration electrons which strike a counter of the third group, can be inferred as follows. If we put

$$\Delta_f = (\text{III}-\text{IV})_{\text{with Fe}}; \quad \Delta_0 = (\text{III}-\text{IV})_{\text{without Fe}},$$

the counting rates $m_f$, $m_0$ of the mesons are given in the two cases by the equations

$$\begin{aligned} m_f &= \Delta_f - p(\text{IV})_f \pm (\Delta_f)^{\frac{1}{2}}, \\ m_0 &= \Delta_0 - p(\text{IV})_0 \pm (\Delta_0)^{\frac{1}{2}}, \end{aligned} \tag{1}$$

where

$$p = p_0/(1-p_0) \quad \text{and} \quad p_0 = 1 - QT_{123}. \tag{2}$$

$Q$ is the undelayed quadruple coincidence and $T_{123}$ the undelayed triple coincidence ($Q/T_{123}$ = IV/III for random coincidences). In deriving formula (1) it must be emphasized that, because of the little delay introduced, the random coincidences are essentially caused by the fluctuations in the steepness of the counter pulses (delay random coincidences $RC$). These $RC$ rates would be the same in the two cases (with and without iron) if slight changes in the operating potentials of the counters did not occur during the measurements. In order to become independent of such variations we preferred to obtain separately the corrections $p(\text{IV})_f$, $p(\text{IV})_0$ instead of eliminating them as if they were equal. In order to obtain $m$, it is necessary to subtract integrally $m_0$ from $m_f$, the counting rate $m_0$ owing to the disintegration electron—(coming from the walls of the counters and from the 1 cm of lead beneath the third group)—which are still all present in the counting rate $m_f$ measured with 0.6 cm of iron on account of their high penetrating power. In conclusion

$$m = m_f - m_0.$$

The results of this first kind of measurements are summarized in Table I. The measurements reported in Table I had been previously divided in partial series relating to successive periods of the experiment in which the counter potentials and the introduced delay had undergone slight variations. In putting together these partial series the necessary corrections have been introduced as described in our previous paper—as a correction to the sum of minutes. However, the value of $m$ thus obtained and reported in the

[9] We thank L. Mezzetti for useful help in performing measurements.

TABLE I. Results of measurements with an absolute delay $\vartheta = 1.025$ μsec.

| Absorber | III | IV | Corresponding minutes | Percentage | $\Delta - p\text{IV}$ hour | m/hour |
|---|---|---|---|---|---|---|
| 0.6 cm iron | 2.942 | 2.311 | 13.558 | 5.2 | 2.26±0.11 | 1.19±0.15 |
| without iron | 1.565 | 1.345 | 8.423 | 5.2 | 1.07±0.11 | |

TABLE II. Results of measurements without delay.

| Absorber | $D_{12}$ | $T_{124}$ | Minutes | $(D_{12}-T_{124})$/hour | $A_5$/hour | $A$/hour |
|---|---|---|---|---|---|---|
| 5-cm iron | 143.520 | 132.120 | 1.105 | 619.0±5.8 | 129.1±7.8 | 15.5±0.94 |
| without iron | 139.632 | 130.912 | 1.068 | 489.9±5.3 | | |

last column of Table I, is not sensibly different from that given by the simple formula $m = \Delta_f - \Delta_0$ without introducing any corrections.

The second type of measurements allows one to obtain the counting rate $A_5$ of the mesons stopped in 5-cm iron. We have, in fact (the meaning of the symbols is obvious): $A_5 = (D_{12} - T_{124})_f - (D_{12} - T_{124})_0$ while the number $A$ of the mesons stopped in an iron plate 0.6 cm thick (during an hour) is given by $A = (0.6/5)A_5$. Table II contains the results of these measurements. The counting rate $M$ of the mesons disintegrating in the 0.6-cm iron can be obtained from the equation

$$m = \bar{\alpha} e^{-\vartheta/\tau}[1 - e^{-T/\tau}]M \tag{3}$$

where the ratio $\bar{\alpha} = \langle\Omega\rangle/4\pi$ between the mean solid angle permitted for the disintegration electrons and the total solid angle, has been calculated very carefully.[10] We take into account:

(a) The geometrical limitation due to the presence of the lateral counters of anticoincidence (Fig. 1a).

(b) The mean range ($\sim$2.7 cm[11]) of the decay electrons in iron.

(c) The "weight" (incident intensity) relative to each point of the iron plate.

(d) That the hard component intensity varies almost as the square of the cosine of the zenith angle. We took into account this last circumstance only approximatively. We verified that the corresponding correction is very small ($\sim$1.5 percent, while correction (c) is 4.5 percent). The result of our calculations was: $\langle\Omega\rangle = 3.98$. Using $\vartheta = 1.025$ μsec. and $T = 3.40$ μsec., formula (3) and the data contained in the last column of Tables I and II and taking $\tau = 2.3$ μsec., we obtain

$$\eta = M/A = 0.49 \pm 0.07.$$

Since during the measurements, the resolving power $T/2$ did not remain strictly constant—(the value $T = 3.4$ μsec. is a mean value)—and considering (see Section 2) that the measurement of the absolute delay is known with certain inaccuracies, it is useful to estimate an upper limit of the ratio $\eta$. Taking $\vartheta = 1.2$ μsec.; $T = 3.0$ μsec., we obtain

$$\eta = 0.56 \pm 0.08.$$

The value $T = 3.0$ μsec. is smaller than the minimum value obtained in the measurements, while the value $\vartheta = 1.20$ μsec. is certainly too high.

The agreement of the corresponding value of $\eta$ with that obtained above shows that the errors affecting $\vartheta$ and $T$ do not influence markedly the value of $\eta$.

### 4. MEAN RANGE OF THE DECAY-ELECTRONS

From our measurements an indication of the value of the mean range $P$ of the disintegration electrons in iron can be obtained by comparing the results contained in Table I with those obtained with the same absolute delay 1.025 μsec. but with 5-cm iron instead of 0.6 cm. For such a purpose we point out that, if the third group of counters could be represented as an indefinite area, the permitted solid angle $\Omega(s)$ would be the same for all electrons produced at the same deepness $s$ of the iron absorber and it would be given by the formula

$$\Omega = 2\pi(1 - x), \tag{4}$$

where $x = s/P$.

This formula is correct for relatively great

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[10] We thank C. Festa for useful help in performing calculations.

[11] This value is based on the calculation of H. Bethe and W. Heitler, Proc. Roy. Soc. **A146**, 83 (1934), about which some doubt can be raised: the work of these authors is antecedent to the theory of multiplicative processes and has been performed disregarding the electron scattering. However correction (b) is very small on account of the small thickness of the iron plate we have used and of the presence of the lateral anticoincidence counters. Moreover, as we shall see later, the experimental value that we found for the mean range of the decay electrons is in satisfactory agreement with the theoretical value of Bethe and Heitler.

values of the depth $s$ and for the most of the points of the corresponding horizontal plane but it cannot be applied for the peripheric points; moreover, for small value of $s$ the angle $\Omega(s)$ is essentially determined by the geometrical arrangement. The behavior of the function $\Omega(x)$ has been sketched in Fig. 5 (full curve) where the value $\langle\Omega\rangle$ of $\Omega(x)$ is that calculated in order to obtain the coefficient $\bar{\alpha}$ (3) and $\bar{x}$ ($\cong 0.365$) has been derived from $\langle\Omega\rangle$ using (4). Assuming *a priori* $5/P>1$; $0.6/P=x<\bar{x}$ the ratio $\nu=m/m'$ between the effects $m$ and $m'$ observed, respectively with 0.6- and 5-cm iron, will be given by

$$\nu=\frac{\langle\Omega\rangle x'}{\langle\Omega\rangle\bar{x}+\frac{1}{2}(1-\bar{x})}=\frac{2x'}{1+\bar{x}};$$

by this equation we deduce:

$$x'=\tfrac{1}{2}\nu(1+\bar{x}). \qquad (5)$$

The $m$ value can be derived from the experimental results, already published, obtained with the same absolute delay (corresponding to the delaying element $R_1$) and with (and without) 5 cm of iron. The corresponding counting rates $m_f'$, $m_0'$ are

$$m_f'=3.51\pm0.25; \quad m_0'=0.66\pm0.18.$$

In this case, we must not take for $m'$ the difference $m_f'-m_0'$. In fact, as we already pointed out, the counting rate registered without iron is caused by the electrons produced in the walls of the counters and in the 1-cm lead plate beneath the third group of counters. Now, the electrons produced in the walls of the counters should not be subtracted from $m_f'$, because the plate of iron, 5 cm thick, is sufficient to establish the equilibrium conditions between the electrons produced and those which are absorbed. The electrons produced in the 1 cm thick lead plate, should be subtracted but they form the smaller part of $m_0'$ as can be easily recognized by considering the geometrical limitations due to the anticoincidences lateral counters and the fact that in order to be counted each decay-electron should strike a counter of the third set different from that crossed by the original meson (the reactivation period of a counter is $\sim 10^{-3}$ sec.). Omitting their contribution, we have

$$m'=m_f'=3.51\pm0.25;$$

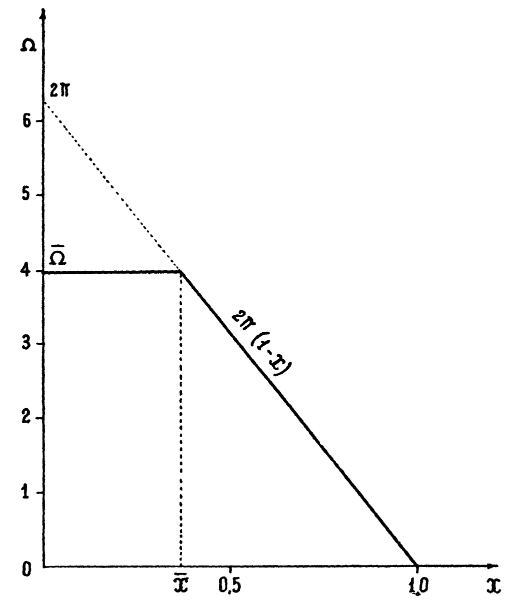


FIG. 5. Variation of the solid angle in which decay electrons are detected, with the thickness of the absorber, taking the range of decay electron = 1.

we find then

$$\nu=m/m'=0.339\pm0.005$$

and using (5)

$$P=0.6/x=2.60^{+0.43}_{-0.34}.$$

Assuming, on the contrary, that the electrons coming from the 1 cm plate of lead represent the 40 percent of $m_0'$ (very likely an excessive value), we obtain

$$P=2.40^{+0.40}_{-0.32}.$$

## 5. DISCUSSION

The results of our measurements suggest that only a fraction of the mesons stopped in a heavy substance undergo the decay process. In fact the value $\eta=1$ seems to be decidedly out of range of the experimental errors. Moreover, the most probable value $\eta=0.49$ seems to indicate that about one-half of the slow mesons disintegrate; this conclusion is confirmed by the upper value $\eta=0.56$.

Our value of $\eta$ agrees pretty well with Rasetti's result[3] ($=0.42\pm0.15$) but does not with that of Auger, Mase, and Chaminade[4]; moreover our result seems to confirm Tomonaga and Araki's theoretical conclusions,[2] because the negative mesons captured by the nuclei would allow disintegration processes with a far too short mean life to be registered with our experimental device. It may be pointed out that, even taking into account the positive excess of the hard component (which amounts to about 20 percent),[12,13] the theoretical value of $\eta$ would not rise to more than 0.6, which is in reasonable agreement with our result. Our result could be explained, also, by assuming that one-half of the hard component is formed by unstable particles having a mean life $\tau=2.3$ $\mu$sec. and one-half by stable particles. This interpretation seems not to be correct on account of the relatively good agreement between the most probable value of $\tau/\mu c^2$ obtained from the experiments on the anomalous absorption and the value derived from direct measurements of $\tau$ and of the mass $\mu$ in the Wilson cloud chamber. If one-half of the particles of the hard component would be stable the observed value of the ratio $\tau/\mu c^2$ ought to be appreciably greater. This last circumstance would not occur according to Tomonaga and Araki's theory, because the capture process of the negative mesons suggested by the theory has a strong probability only at very low energies. Moreover, if one assumes that one-half of the hard component is formed by stable particles having the same sign, one would expect a variation of the positive excess with the total number, while direct experiments showed that such an excess keeps constant between 3500 m above the sea level and the sea level.[14]

In conclusion it seems that Tomonaga and Araki's suggestion represents the best explanation of the experimental result.

A few years ago Dr. E. Pancini suggested an experiment designed to give definitive answer about this point: it consists in measuring the delayed coincidences produced by the disintegration electrons concentrating alternatively the positive mesons and the negative ones by means of magnetized iron blocks. Experiments of this type are now in progress.

From the previous paragraph it follows that our experimental results allow the evaluation of the mean range $P$ of the decay electrons in iron, with a probable error of about 20 percent. Although the experimental error is rather large, one could deduce from our value of $P$ the rest energy of mesons, using the range-energy relation for electrons in iron. Unfortunately, we do not possess at present a reliable formula or experimental data of this type. Bethe and Heitler's calculations are antecedent to the theory of multiplicative processes and disregard the electrons scattering. However, with the help of the formula given by these authors, we find that the value $P=2.5$ cm of iron obtained by us corresponds to an energy $\mu c^2$ of about 90 Mev.

This value of $\mu$, even if it is to be considered only as an indication, gives a further and comfortable connection between the experiments of this kind, dealing with direct measurements on the disintegration process, and the other several experiments concerning the hard component of cosmic rays.

We thank Professor Gilberto Bernardini for his interest taken in our experiments. We thank also Professors A. Bandini, President of the Lyceum-Gymnasium Virgilio, and Professor L. Fagiolo, Vice-President, for their great interest and kindness. The present experiment has been carried out with equipment furnished by the Centro di Fisica Nucleare and the Istituto Nazionale di Geofisica of the Consiglio Nazionale delle Ricerche.

[12] H. Jones, Rev. Mod. Phys. **11**, 235 (1939); D. H. Hughes, Phys. Rev. **57**, 592 (1940).

[13] G. Bernardini, M. Conversi, E. Pancini, and G. C. Wick, Ricerca Scient. **12**, 1227 (1941); M. Conversi and E. Scrocco, Nuovo Cimento **I**, 372 (1943); G. Bernardini, M. Conversi, E. Pancini, E. Scrocco, and G. C. Wick, Phys. Rev. **68**, 109 (1945).

[14] G. Bernardini, M. Conversi, E. Pancini, and G. C. Wick, Ricerca Scient. **13**, 1227 (1941).