Physics. — *Cosmic radiation penetrating into the earth to a depth of 1380 m waterequivalent.* By J. CLAY and A. V. GEMERT.

(Communicated at the meeting of September 30, 1939.)

§ 1. After having finished the measurements concerning the decrease in intensity of the cosmic radiation in layers of water down to a depth of 440 m, which we communicated before [1]), we subsequently examined the decrease in thick layers of rock in the Domanial Coal Mine at Kerkrade to a depth of 620 m. In the first place we measured with the same apparatus as was used for the determination in water and thus it was possible to make a comparison for a thick layer between the decrease in water and in slate.

Secondly, since in the mine at the various depths we had an opportunity to continue the observations longer, we were able to obtain fairly accurate data on the intensity also at a great depth. The accuracy was possible by the construction of two new counter systems, which had a large surface, so that at sea-level with interposition of 2 layers of lead of 5 cm still 160 threefold coincidences per min. could be counted.

§ 2. In the mine measurements were made at 8 different levels, the values of which are given in Table 1 column 1. In order to determine with how much waterequivalent this corresponded, the measurements of the first four layers were compared with the values found in water (column 3).

TABLE 1.

Depth h.	Eq. according to density h_s	According to measurements water-eq. h_e	$\frac{h_s}{h_e}$	Watereq. $\frac{h_s}{1.19}$
0	10	10		
43	101	85	1.19	85
102	260	204	1.27	219
143	370	287	1.29	311
195	510	427	1.19	427
255	672			563
375	992			835
495	1320			1107
615	1644			1380

[1]) J. CLAY, A. V. GEMERT and P. H. CLAY. Proc. Kon. Ned. Akad. v. Wetensch., Amsterdam, **41**, 694 (1938).

In fig. 1 data have been reproduced of 110 to 452 m water depth and the values of the 4 stations have been plotted on them. It appears that these

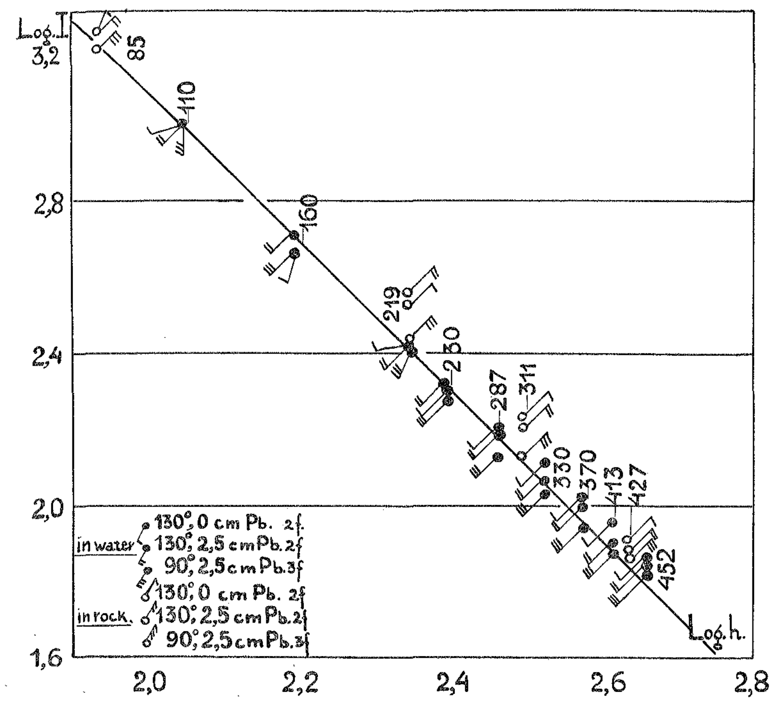

Fig. 1. Comparison of the decrease of intensity in water and rock down to 450 m waterequivalent. Twofold, 0 cm *Pb*, 130°; twofold 2,5 cm *Pb* 130°. Threefold 2,5 cm *Pb* 90°.

values lie partly on the same straight line. It will be best to compare the values of the threefold coincidences with 2,5 cm lead absorption, i.e. the bundle from which the soft secondaries have been removed most. From the further observations it appears, that at the depths of 219 and 311 m waterequivalent a greater amount of secondaries occurs and in the rocks more than in water.

Whereas formerly we thought that the absorption in different substances was proportional to the density, we found by these measurements for the first time that this is not correct, for, while according to a series of density determinations the column of 195 m of rock had to be equal to 510 m of water, this layer in reality appeared to be equivalent to 427 m (Table 1). The fact that, as regards the thickness of the layers, we could make use of the obtained values of the specific weight and the directly measured depths became apparent from a control performed by Dr. NIEUWENKAMP. At a depth of 615 m a gravitation measurement was made by means of a Hollweck pendulum and he found that the total density above this layer was 2,52 ± 0,10, whereas we found an average density for 0,—37 m of 2,12 and for 37—615 m of 2,70 or averagely 2,66. The proportion of the absorption of the rays to that in water appeared to be 2,25 and henceforth we reduced all our depths below the rock in this way. Later on we shall advance arguments that this ratio of the absorption also applies to other substances, such as lead and iron.

§ 3. We shall now first give the results of the 3 instruments at different

TABLE 2.

Threefold coincidences at different depths.

0 cm Pb.

Depth in m	Watereq. in m	Log.	Time	Number	Number per min.	Reduced	Log.
0	10	1.00	30′	5170	172 ± 2.40	22400	4.35
43	85	1.93	58′	445	7.67 ± 0.364	1000	3.00
Paraffin			510′	3834	7.52 ± 0.122	981	2.99
102	219	2.34	2607′	3150	1.21 ± 0.022	158	2.20
143	311	2.49	2758′	1525	0.553 ± 0.014	72.1	1.86
195	427	2.63	12658′	3198	0.253 ± 0.004	33	1.52
255	563	2.75	10110′	972	0.0961 ± 0.0003	12.5	1.10
378	835	2.92	16520′	515	0.0312 ± 0.0014	4.1	0.61
498	1107	3.04	10032′	150	0.0150 ± 0.0012	1.96	0 29
619	1380	3.14	51134′	310	0.0061 ± 0.0002	0.79	0.90—1
5 cm Pb,							
0	10	1.00	30′	4799	159.9 ± 2.31	21800	4.34
43	85	1.93	1184′	8703	7.34 ± 0.078	1000	3.00
102	219	2.43	6893′	8042	1.17 ± 0.013	159.1	2.20
143	311	2.49	1690′	852	0.504 ± 0.014	68.7	1.84
195	427	2.63	1163′	338	0.290 ± 0.016	39.5	1.60
10 cm Pb.							
0	10	1.00	24′	3856	160.5 ± 2.58	22500	4.35
43	85	1.93	1142′	8132	7.11 ± 0.079	1000	3.00
102	219	2.43	6805′	7785	1.14 ± 0.013	160	2.20
143	311	2.49	1185′	585	0.493 ± 0.020	69.2	1.84
195	427	2.63	7702′	1521	0.197 ± 0.005	26.9	1.43
255	563	2.75	2819′	452	0.0802 ± 0.0038	11.24	1.05
498	1107	3.04	53277′	707	0.0132 ± 0.0004	1.85	0.28

TABLE 3.

Threefold coincidences at different depths.

10 cm Pb.

Depth in m	Time	Number	Number per min.	Reduced	Uncertainty	Log. I
10	360′	3929	10.9 ± 0.174	15850	1.8 %	4.2005
85	1374′	946	0.689 ± 0.0224	1000	3 %	3.000
219	11484′	1338	0.117 ± 0.0032	170	2 %	2.230
311	2873′	177	0.0617 ± 0.0046	897	9 %	1.953
427	8567′	126	0.0147 ± 0.0013	21.3	10 %	1.328
100 cm Pb.						
10	360′	3586	9.95 ± 0.017	15500	1.8 %	4.1903
85	2221′	1499	0.675 ± 0.017	1000	3 %	3.000
219	5229′	543	0.102 ± 0.004	162	4 %	2.2095
311	4055′	230	0.0567 ± 0.004	89.2	6 %	1.9500
427	8519′	118	0.0138 ± 0.003	21.5	10 %	1.3320

depths. After making determinations at a depth of 615 m, we have further in as many places as possible also carried out measurements with 5 cm *Pb* and 10 cm *Pb* between the counters and finally in the layers to 429 m waterequivalent measurements were made with 10 cm *Pb* and 100 cm *Pb* between the counters, the distance between the outer counter systems being 125 cm. Besides, at the various depths were registered the number of times when the two systems, placed side by side, reacted at the same time; this consequently represented the number of showers under these special conditions. We shall revert to this later on.

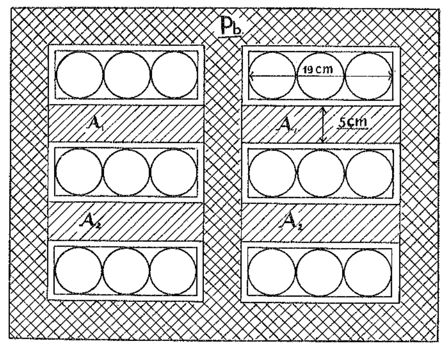

Fig. 2. Arrangement of the two counter systems for the measuring of threefold coincidences and of showers.

During the measuring of the coincidences there was no lead in A_1 and in A_2 or 5 cm in A_2 or 5 cm in A_1 and A_2. For the measuring of the showers there was no lead in A_1 and A_2.

The measurements were made while the counters were constantly surrounded by a screen of 5 cm *Pb*, as in fig. 2. With the shower measurement there was no lead between the counter-boxes in A_1 and A_2.

Consequently the number of individual impacts as the result of the radio-activity of the soil was reduced in such a way, viz. from 900 to 120, that the number of incidental ones might be wholly neglected. Since the duration of discharge appeared to be 2 10^{-6} min, in agreement with this value the number of incidentals per day was less than 1, so that no correction was necessary. A small correction only was necessary at sea-level.

In table 4 it has been stated how large is the number of coincidentes

TABLE 4.

Threefold coincidences at 1380 m waterequivalent.

19 Oct. till 7 Nov. '38	Time in min.	Number of coincidences		
		G.I	G.II	N_1 (Bergen App.)
20	1332	12 (3)	8 (0)	
21	1427	8 (1)	6 (2)	
22	1396	5 (4)	10 (2)	
23	—	—	—	
24	2848	22 (4)	14 (2)	7
25	1406	10 (1)	10 (2)	4
26	1407	5 (4)	8 (0)	4
27	1464	14 (5)	6 (2)	2
28	1401	14 (5)	8 (0)	3
29	—	—	—	
30	2823	14 (4)	12 (4)	3
1	—	—	—	
2	2656	12 (6)	16 (5)	10
3	1398	6 (3)	11 (3)	4
4	1434	9 (0)	9 (1)	4
5	1472	12 (3)	9 (1)	2
6	—	—	—	
7	3103	21 (3)	21 (5)	7
	25567	164	148	50
Mean value p. min.		0.0064 ± 0.0005	0.0058 ± 0.0005	0.0023 ± 0.0003

The numbers between brackets are the differences from the mean.

observed per day in the two instruments *G I* and *G II*, constructed in the same way, and in the apparatus *N*, which formerly was also used for

the determinations in water. From this we see that in these two apparatuses equivalent values were found, while in all instruments, in spite of the fact that the opening angle differed and the interposed lead was not equal, the decrease with respect to the value at sea-level differed but slightly, as may be observed in the data of the tables as well as in fig. 3.

In this figure the decrease has been indicated from 85 m waterequivalent

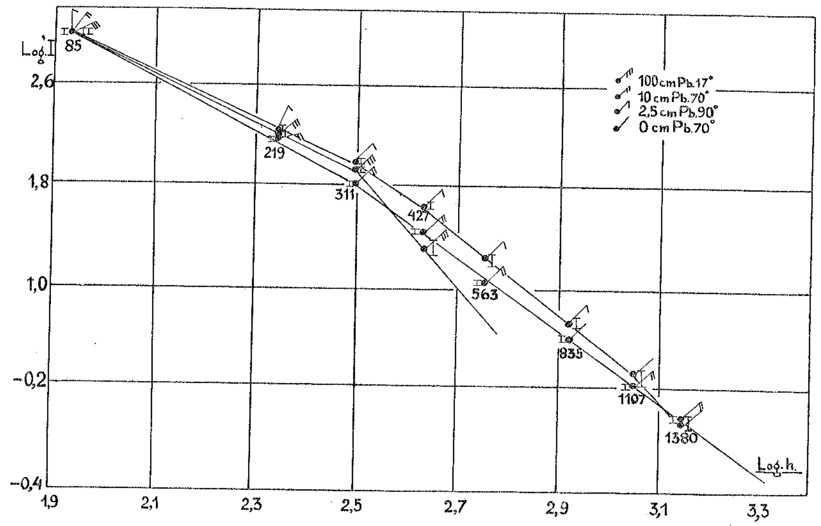

Fig. 3. Decrease of intensity between 85 and 1380 m waterequivalent with different systems of counters without lead and with 2,5 cm *Pb*, opening 140°; 5 cm *Pb*, 10 cm *Pb*, opening 70°. Comparison with 10 and 100 cm *Pb* between the counters opening 17°, between 85 and 427 m waterequivalent.

onwards and for layers of lead of different thickness between the counters. From the lines we see that the differences for the different thicknesses of the lead are not large, except that for 100 cm *Pb* the line below 311 m forms a steeper descent. The figure shows that for greater depth the slope grows steeper. For waterequivalent depths from 85 m to 311 m the decrease is

$$I_h = I_0\, h^{-1,93} \qquad 85 < h > 311\ m$$

and for the values below that depth, the narrower cone with 100 cm *Pb* being taken as basis, we find

$$I_h = I_0\, h^{-2,95} \qquad 311 < h > 1380\ m.$$

These values have an accuracy which is indicated by the arrows and may be found in column 6 of table 2.

§ 4. The measurements with 100 cm *Pb* between the counters enable us to draw a conclusion concerning the nature of the primaries, as they penetrate into the deep strata. By BARNOTHY and FORRO [2]) and initial by

[2]) J. BARNOTHY and M. FORRO. Phys. Rev. **53** (1938).

WILSON [3]) it had namely been suggested that the primary rays which penetrate so far might perhaps be uncharged neutrinos and what was measured in counters could then only be secondary. We could now determine the decrease of the primary rays in each point from the decrease along the whole area by means of the formula $I = I_0 h^{-n}$ and with the water equivalence of the lead, which now we know, find the decrease to be expected of the primaries in 90 cm of lead. This decrease is given in column 2 of table 5. It should be remarked here that for sea-level the

TABLE 5.

Decrease in 90 cm Pb calculated and measured at different layers in %. Total number of secondaries.

Watereq.	Calculated decrease of primaries. in 90 cm Pb Formula 1	Measured decrease by (100—10) cm Pb	Difference	Second. absorbed in 10 cm Pb	Total of second.
10	(27) %	35 %	(8)	(12)	(20)
85	14 %	15 %	1	7	8
219	5.5 %	12 %	6.5	5.8	12.3
311	3.7 %	8 %	4.3	11	15.3
427	5.6 %	6.3 %	0.7	22	22.7

decline of the mesons must be taken into account. Here it should be remarked that at 10 cm (sea-level) another decrease of the primaries applies, which may be found from a formula, calculated by BRUINS [4]) taking into account the decay. In the third column we mentioned the measured decrease. The fourth column gives the difference, consequently indicating the number of secondaries in percentages which still can penetrate through 10 cm *Pb*. In the last column may be found the number of secondaries removed by 100 cm *Pb*, i.e. practically all. In column 3 the measured decrease is given. In column 4 the difference between these two values is given, by which consequently is determined the number of secondaries yet penetrating 10 cm of lead. In column 5 we gave the number of secondaries which is removed by 10 cm *Pb* and in the last column we consequently find the total number of secondaries. This is calculated in so far as we may assume that secondaries are not able to penetrate through a meter of lead, which in any case is impossible for electrons. We may consequently state that the decrease found in 1 m of lead in several points corresponds with the supposition that all primaries are ionizing rays and that only in the area from 219—311 m waterequivalent a larger number

[3]) V. C. WILSON. Phys. Rev. **53**, 337 (1938).

[4]) E. M. BRUINS. Proc. Kon. Ned. Akad. v. Wetensch., Amsterdam, **42**, 740 (1939).

of rays is removed than is in agreement with the decrease of the primaries.

Consequently there are here a number of secondaries which yet can penetrate through 100 cm of lead. This is for the rest in perfect agreement with what may be expected from other data.

§ 5. At a depth of 427 m waterequivalent, however, there is no reason to assume that there are no ionizing primary rays. As we can see from the table, at that depth the number of rays is reduced to one thousandth of the number at sea-level. This conclusion does not agree with that of BARNOTHY and FORRO [5]). They recently published the results of measurements at a depth of 980 m waterequivalent, — 821 m according to the above-mentioned results. They find that the value at this depth is 0.15 % of the radiation at sea, whereas we find 0.017 % at 834 m waterequivalent. In our measurements, however, there is no indication that the number of secondaries at the great depths is so much larger than at smaller

TABLE 6.

Showers

Twofold under 5 cm Pb

M. watereq.	Time	Number	Number p. min.	Reduced	Log.
10	1020	1208	1.185 ± 0.03	6600	3.82
85	1142	195	0.171 ± 0.01	930	2.97
219	1425	54	0.0379 ± 0.005	206	2.31
311	4400	92	0.0209 ± 0.002	114	2.06
427	2344	60	0.0256 ± 0.003	139	2.14
563	5055	53	0.0105 ± 0.001	57	1.76
(10 cm Pb (563)	2819	4	0.0015)		
835	7700	24	0.0031 ± 0.0006	17	1.23
1107					
1380	25567	3	0.00012 ± 0.00007	0.64	0.81—1
Threefold					
10	574	819	1.425 ± 0.0497	7900	3.90
85	1184	218	0.184 ± 0.0125	1000	3.00
219	4351	148	0.034 ± 0.00279	185	2.27
311	2869	103	0.0362 ± 0.00356	200	2.30

[5]) J. BARNOTHY and M. FORRO. Phys. Rev. **55**, 870 (1939).

depths. On the contrary, we find that the number of secondaries removed by 10 cm *Pb* below 427 m waterequivalent grows smaller, as also the number of showers at the greater depths decreases again.

§ 6. The number of showers found at different depths is given in table 6 and in fig. 4 a comparison is made with the decrease found by WILSON. The showers were measured by placing the two instruments side

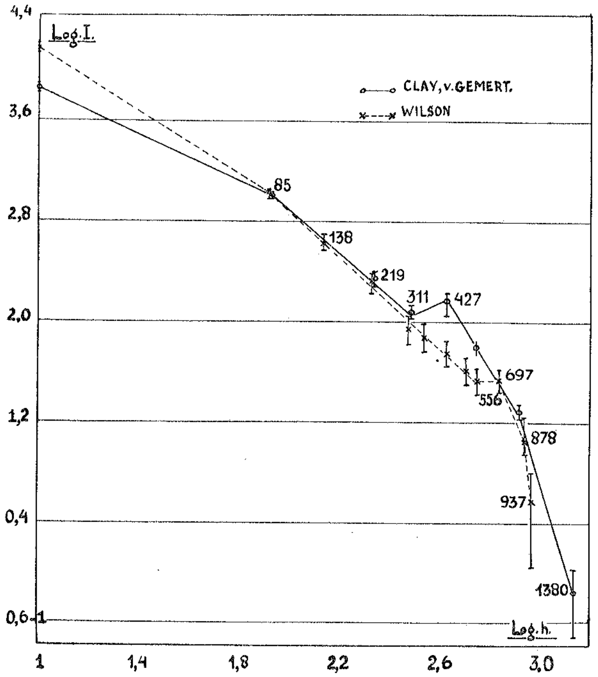

Fig. 4. Comparison of decrease of the showers in the rock, down to 1380 m waterequivalent.

by side, as is reproduced in fig. 2. However, in order to be able to make a comparison with other shower determinations, also for the highest four layers threefold showers were measured by placing the three boxes side by side by the method indicated in fig. 5 without lead above the boxes. From these figures we can see that the numbers at 85 m and 219 m differ but little from the twofold showers measured in a different way. At 319 the difference was somewhat larger. At 563 m still showers were measured with 10 cm *Pb* between the counters and we see that thus the number was reduced to one seventh. The majority of the shower rays consequently have a slight penetrative power and must chiefly consist of electrons. Here we touch a point on which at the moment opinions differ

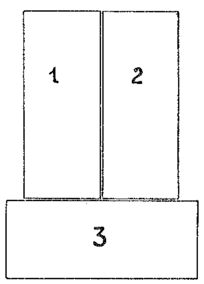

Fig. 5. Arrangement of the counter-boxes for threefold coincidences.

greatly. The results of different authors are totally conflicting. Some, like JANOSSI [6]), find from counter measurements that at sea-level no mesons occur in showers. The photos by STREET and FUSSELL [7]) on the other hand leave no doubt that in some cases there are showers consisting of mesons.

§ 7. We will now further consider the conclusions which may be drawn from the course of the decrease and the number of secondaries at different depths. In table 7 in the second column is given the difference

TABLE 7.

M. water eq.	130°, difference between 0 cm Pb and 2.5 cm Pb in %	70°, diff. between 0 cm Pb and 5 cm Pb in %	70°, diff. between 0 cm Pb and 10 cm Pb in %	17°, diff. between 10 cm Pb and 100 cm Pb in %	Showers primaries in % 2 f.	Showers primaries in % 3 f.
10	16	12.4	12.4	35	0.74	0.89
85	10.7	4.3	7	15	2.4	2.6
219	13	2.5	5.8	12	3.8	3.0
311	18	10	11	8	4.3	7.3
427	16	18	22	6.3	13	
563			17		13	
835					10	
1107			12			
1380					2	

measured with the old apparatus without lead between the counters and with 2,5 cm *Pb* measured in the wide cone. In column 3 the number removed by 5 cm *Pb* in the narrower cone, in column 4 the number removed by 10 cm *Pb* between the counters, all in percentages with regard to the number left between the counters after 10 cm *Pb*. In column 5 the number removed more by 100 cm *Pb* than by 10 cm *Pb*. In order to find the number of secondaries, the primary rays removed by absorption have to be determined. They are found from

$$I_h = I_0\, h^{-1{,}93}$$

and this calculated difference is given in column 2 of table 6. In fig. 6 the

[6]) L. JANOSSY, Proc. Cambr. Phil. Soc. **34**, 614 (1939).
[7]) FUSSELL, c.f. J. C. STREET, Journal of the Franklin Inst. **227**, 765 (1939).

curves indicate the number of secondaries at different depths. At the same time the course of the showers in proportion to the number of primaries

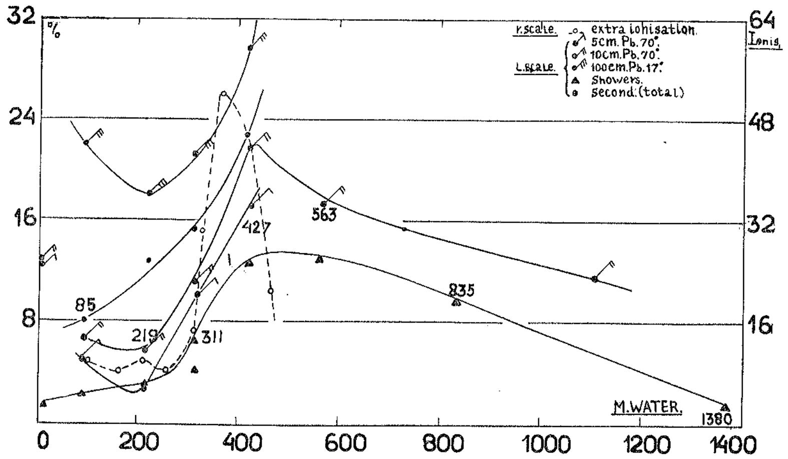

Fig. 6. Secondaries and showers at different depths in % of the primaries (left scale).
Extraionization in % of the primaries (right scale).

is given and finally the excess of ionization at different depths expressed in the ionization which would be obtained if the ionization took place simply in proportion to the intensity of the primaries. Here the scale on the right may be read. From all this it is apparent that the number of secondaries in proportion to the primaries increases considerably from a depth of 200 to 400 m and that further it decreases, the course of the showers showing the same phenomenon. It is besides evident that the effect of this increase must be far more strongly felt in the ionization, this indicating the total effect of showers, while a whole bundle of rays as showers and as secondaries is only counted as 1.

Is there a possibility to explain this excess of secondaries? In our opinion this may be formed in the following way.

The radiation of corpuscular particles is inversely proportional to the square of the mass of the particles. This radiation consequently starts with mesons with a mass of about 100, with energies of the particles lying between 10^{11} and 10^{12} e Volt, and increases with the energy. From the obtained energy spectrum,

$$N(E) = N_0 E^{-(n+1)}$$

being given, we may now conclude that the average energy of the particles which penetrate through a certain layer is twice the amount of energy required for the penetration of a special layer. Various data showed that for the penetration of 10 m of water $2{,}5 \times 10^9$ e Volt is required. For 200 m this is consequently 5×10^{10} e Volt, so the average energy of the particles at that depth is 10^{11} e Volt and then increases and with it the

radiation increases as well. Below 400 m waterequivalent the radiation seems to be of another nature. In the first place the decrease is stronger than in the shallow part $I_h = I_0 h^{-2{,}95}$. Consequently the distribution of energy is more rapidly decreasing for this radiation. The fact that the radiation is ionizing is evident from the decrease at 427 m, which in 90 cm *Pb* corresponds with the decrease which may be derived from the difference between 311 and 427 m. The number of secondaries decreases as well as the number of showers, the radiation therefore seems to be less intense, which points to a greater mass of the particles. Without, for the present, making new hypotheses, we should consequently have to conclude that these rays are protons. The number, however, is very small. The total number of rays within a certain cone has at 427 m waterequivalent already decreased to 1,5 ‰ and at 1380 m waterequivalent is yet 0,035 ‰ of sea-level.

§ 8. In connection with the supposition that the penetrative component of the radiation consists of mesons which have a rest mass of about 100 m_0 (m_0 is rest mass of the electron) and on the ground of the view that these particles are identical with the binding particles in the atomic nuclei and the latter are a link in the binding of the particles of the nucleus, it has been suggested that these mesons are unstable and have a lifetime proportional to the energy. For the rest energy this would amount to $\tau = 2 \times 10^{-6}$ sec. This supposition now explains among other things why the decrease in the upper layers of the water is smaller than in the atmosphere and the deeper layers of the water.

From the difference of this decrease and the decrease found in water, where the decline no longer plays a part, by various authors as EULER and HEISENBERG, EHRENFEST and FRÉON [8]) and from our measurements the times of decline was calculated at $1{,}5 \times 10^{-6}$ by BRUINS [9]) and by P. H. CLAY at $1{,}9 \times 10^{-6}$ sec.

There is yet another method by which this may be done. Upon determination of the absorption in various directions in the atmosphere it is found that the radiation in directions which form a large angle with the vertical decreases far less for a special thickness of the lead than in vertical direction. Owing to the long path in oblique direction, namely, all particles with slight energy have fallen out and thus it may be explained that rays forming an angle of 75° with the vertical are so hard that in the first 40 cm *Pb* the radiation hardly decreases at all. This implies that the minimum energy must be of the order of 5×10^9 e Volt. BRUINS [10]) has exactly calculated the decrease in the various directions and from this it

[8]) H. EULER and W. HEISENBERG. Ergebn. d. Exact. Nat. **17**, 1 (1938).
P. EHRENFEST and A. FRÉON. Journal de Phys. et du Rad. VII, **9**, 529 (1938).

[9]) E. M. BRUINS. Proc. Kon. Ned. Akad. v. Wetensch., Amsterdam, **42**, 54 (1939).
P. H. CLAY. Physica, **6**, 82 (1939).

[10]) E. M. BRUINS. Proc. Kon. Ned. Akad. v. Wetensch., Amsterdam, **42**, 740 (1939).

may be derived how the spectrum must be in various directions for different times of decline in the supposition that the mesons are liberated at a height of 20 km. The observed curve (cf. fig. 7) for the vertical radiation resembles

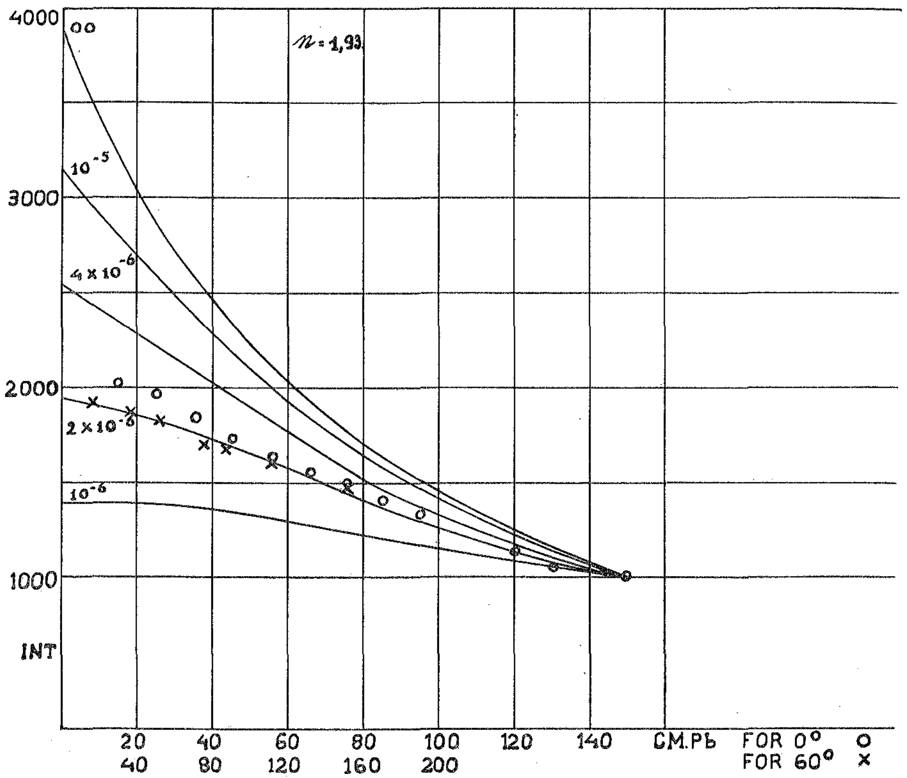

Fig. 7. Decrease of hard corpuscular rays in layers of lead up to 150 cm in vertical direction (o) and in a direction of 60° with the vertical (×) compared with the theoretical curves calculated by Bruins for different lifetimes of the mesons.

most one where the time of decline is just over 2×10^{-6} sec. and for a slope of 60° the value corresponds with 2×10^{-6}. In figure 8 the decrease in lead for vertical direction has been given. For a gradient of 60° two series of measurements have been made and besides a series is measured for an angle of 45° and one of 75°. It may be seen that the decrease in these directions is much smaller than in the vertical direction. In fig. 7 it has then been stated which decrease is to be expected for different lifetimes. The circles indicate the observed value in vertical direction, the crosses that of 60°. In the graph of fig. 8 we started from the value with 15 cm *Pb* between the counters, since at that thickness of the lead the secondaries are eliminated. The number of secondaries is found by the decrease which is the result of 15 cm *Pb* between the counters. We see that for the vertical direction and for 60° the number is the same, in spite of the fact that in

the latter case not so many penetrate. In the direction forming 75° with the vertical the number of secondaries is considerably larger.

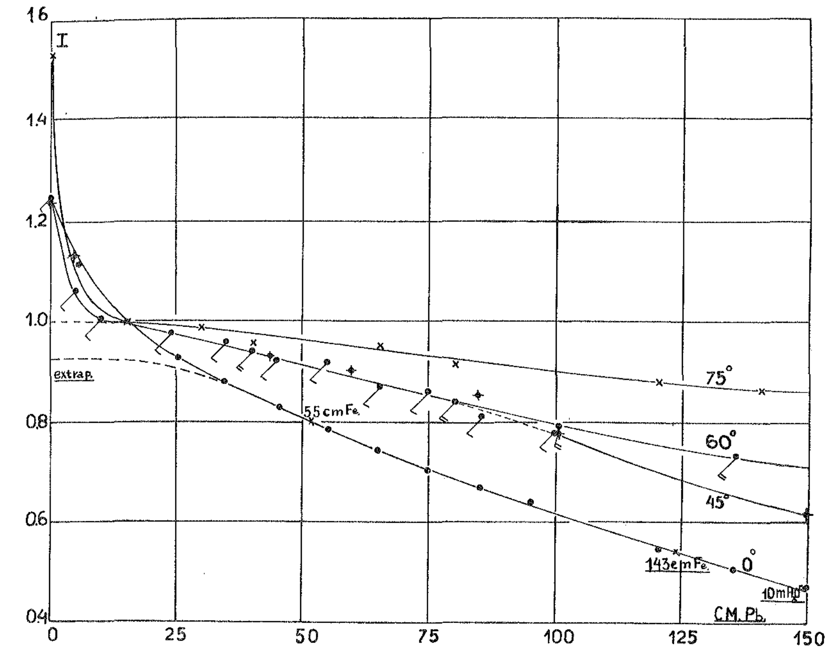

Fig. 8. Decrease of the corpuscular radiation in different directions. In vertical direction a comparison with the decrease in 10 m of water and in 55 cm *Fe* and 143 cm *Fe*.

§ 9. The decrease in radiation was compared for various substances. In addition to water and slate we could now determine this for lead and iron. For this purpose we placed three counter apparatuses in such a way that 50 cm *Pb* could be interposed between the counters and besides an amount of lead of 60 cm above the counters. In this case the opening angle of the cone was 16° breadthwise and 36° lengthwise, while the measurements in water yielded an opening of 30° in both directions. During the measurements in water we had 5 cm *Pb* between the counters. From the

TABEL 8.

	Density	Electrondensity	Electr. density H_2O	Absorpt. in water	Absorpt. electr. density
Water	1	3.40×10^{23}	1	1	1
Slate	2.7	8.3×10^{23}	2.41	2.3	1.06
Iron	7.8	21.9×10^{23}	6.44	5.6	1.12
Lead	11.3	27.40×10^{23}	7.9	6.9	1.12

measurements with lead it appeared that 150 cm *Pb* yielded the same decrease as 10 m of water + 5 cm *Pb*. Then lead could be replaced by iron and thus the decrease in iron and lead could be compared. In the figure 8 the obtained values have been indicated for 10 m of water and those for 143 cm *Fe* and 55 cm *Fe* with regard to those of lead.

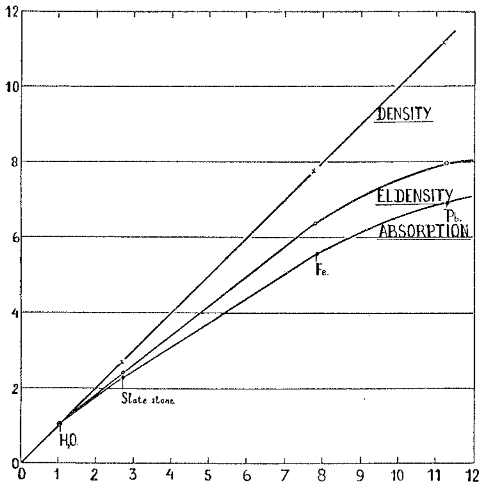

Fig. 9. Comparison of the absorption of penetrating cosmic rays in different materials. The abscissa give the densities. The ordinates are the electron densities and the absorptions in relation to the absorption in water.

However, we have to bear in mind here that this is the ratio of the losses of energy for the rays at sea-level, i.e. that bundle of rays in which still energies of 10^9 e Volt occur. For a bundle of higher energies the ratio might differ, the radiation in lead beginning at a lower energy than in water.

From these measurements it appeared that 6,9 m of water was equivalent to 1 m of lead. In table 8 the density and the proportion of absorption to that in water have been given as well as the proportion of the decrease to the density of the electrons. It is evident that the absorption in water with respect to lead and iron agrees more with the density of the electrons than with the density itself, while it is also correct, if the average binding of the electrons plays a part, that towards the heavier elements the absorption grows somewhat less than is in agreement with the density of the electrons. That this density of the electrons plays a part is also in agreement with the fact that now we know that the loss of energy below 10^{11} e Volt is almost exclusively a loss due to ionization. Finally it may be remarked that the results agree remarkably well with the calculation by BHABHA [10]), who for the ratio of the absorption in lead and in water for mesons of 10^{11} e Volt found 7,2.

In conclusion we wish to express our thanks to Dr. NIEUWENKAMP for his gravitation measurement in the Domanial Mine at a depth of 615 m. To the Managing Director, Ir. FOCK, and to the staff of the Domanial Mine we are greatly indebted for their great willingness and help and to Prof. VAN POELJE and Mr. D. H. VAN DAM for the financial assistance which by their mediation could be given for these researches.

10) H. BHABHA. Proc. Roy Soc., London, **164**, 257 (1938).

Anatomy. — *Index curves* [1]) *of Pygmy and Veddoid tribes. Dravidian influences in the Indian Archipelago.* By C. U. ARIËNS KAPPERS.

(Communicated at the meeting of September 30, 1939.)

While there is no doubt that the ulotrich Pygmy tribes are no race of their own, but should be grouped together with the taller ulotrich Melanoderms [2]), it is a striking fact that these dwarfish tribes show much greater differences in their index curves than the taller Melanoderms from those circumequatorial regions where they live and to whom they may be related.

Practically all the tall Melanesian, Indian and African Melanoderm tribes are meso-dolichocephalic [3]).

On the contrary among the Pygmies next to meso-dolichocephalic groups some tribes occur which, as a whole, are brachycephalic viz. the Mincopies of the Andaman islands and the Baining of New Britain, while there are also many brachycephalics amongst the Aeta of the Philippines and Pesechem of New Guinea. As these brachycephalic Pygmy tribes only occur in the East, it seemed doubtful to some authors whether these Pygmy tribes might be classified with the predominantly mesocephalic Pygmies from the East and from Africa.

WOO and MORANT even stated that the Mincopies and Aeta's are degenerate Javanese tribes (l.c.i.) a statement, contested by GUHA.

Among the African Pygmies hitherto no tribes are found which as a whole, are predominantly brachycephalic. Although also among them roundheaded *individuals* occur, as a group or groups they are mesocephalic, as are also the Semang from Malacca and the majority of the Melanesian Pygmies.

The mesocephalic Pygmies apparently are the most numerous and most widely spread type.

1) In all our curves the figure 70 stands for 70.00 to 70.99 etc.

2) According to SCHLAGINHAUFEN the Lapps from Kola should be also considered as Pygmies (Pygmäenrassen und Pygmäenfrage, Vierteljahrschr. der Naturf. Ges. in Zürich, 1916, p. 249), but he stands alone in this opinion. — Whereas according to BRYN the stature of the North Norwegian Lapps is 157,4 according to SCHREINER it is even 164,17. Although they are short it is not proved that this shortness is hereditary, the more southern Lapps being taller.

3) With those few African Negro tribes, such as the Western Sara, and the Basoko, Batatela and Malela, who in addition to dolichomesocephalic individuals contain a certain number of brachycephalics, it is even doubtful if the shape of the head of their brachycephalics is not artificially influenced. This holds good especially for the Sara West, measured by POUTRIN. (Contribution à l'étude des Pygmées d'Afrique, l'Anthropologie, Tome **21**, 1910, p. 435). For the indices of these Negroes see Proc. Kon. Akad. v. Wetensch., Amsterdam, **39**, 1 (1936), Table II, fig. 34.