

Physics. — *The soft component of Cosmic Radiation.* By J. CLAY.

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In the cascade theory of electrons is calculated the number and energy distribution of electrons found under a certain layer of matter, produced by one electron of certain energy. But what will be the result of an electron radiation in total, will depend on the energyspectrum of the electrons.

For some years we have already tried to find the number of electrons and their energy but it was impossible to find reliable results on account of different disturbing factors. It seems to be necessary to measure the total number of incoming particles and to subtract the penetrating part, which is 80 % of the total number, to get the number of the soft particles only. To measure the decrease of these soft particles only, it is necessary to find the differences by applying thin layers of material and to find the decrease, in casu some percents of the total number. The constancy of the counters must be very high for this purpose and the numbers measured must be great in a short time, moreover it is necessary to do this in periods of very small barometer changes, — because the barometer variation is 5 % for 1 cm Hg. —; constancy of temperature is necessary and no magnetic-storms may occur. To meet these difficulties we used 5 countersystems. One countersystem controlled the number of the hard component (10 cm between the counters) and another controlled the hard and soft together by using no absorption material. For the determination of the soft component itself three other sets were used. Every set had 3 boxes in series and every box 3 counters parallel with an active surface of 820 cm². The opening cone was 24° and 50°. These counters were placed at distances of about 20 to 60 cm. The number of coincidences was from 120 to 60 per minute. We could measure 7200 to 3600 coincidences p.h. and within a period of 6 hours we may reckon with a natural fluctuation of 0.5 % to 0.7 %. For every layer we measured about 100000 coincidences. Mostly the value of coincidences for one layer of matter was enclosed between two measurements with another layer. We could be certain of the results for 1 % in the total number, that means 5 % in the number of the soft component alone in its full intensity.

With these sets the decrease was measured in Pb., Fe., Al., C., H₂O and paraffin.

We know the formulae of energyloss in different materials and for lead.

these formulae¹⁾ agree with the statistics of ANDERSON and NEDDERMEYER²⁾ between 10^5 and 10^7 e-volt.

When we now take the energy for a certain layer and count the number of particles which can just penetrate this layer, we know the number of particles which have an energy above this limit. We find the integral spectrum $I = C f(E_{\min})$. From this function we find the differential spectrum. It might be necessary to take just the average energy between every two intervals and the numbers which are stopped in this interval, but when the distribution is of the same nature as those of the mesons, we can use an easier way and this seems to be real.

When the integral spectrum is of the form $I = C E^{-(S-1)}$, the differentialspectrum is $N(E) = \frac{dI}{dE} = -C(S-1)E^{-S}$.

If this function holds we may take $\log. I = -(S-1) \log. E$ and $S-1$ is found from the inclination of the line in $\log. I$ and $\log. E$.

At first we took the relation between the energy and the range in lead for electrons given by HEITLER (fig. 1) and so we know the energy

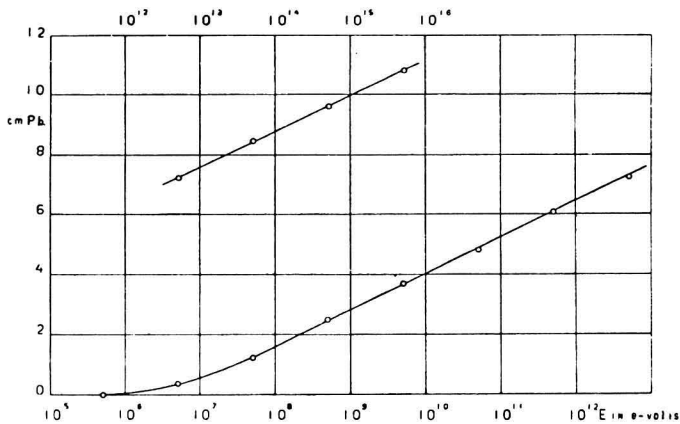


Fig. 1. Range of an electron in lead.

necessary for every layer. Then we put the log. of the remaining number of electrons below the different layers against $\log. E$ and we find the line given in fig. 2. In order to find the remaining number of the total soft rays it is necessary to separate the soft from the hard component. We know from many absorption experiments that the intensity of the total radiation consists in two parts, under more than 10 cm of Pb. the decrease is of another kind as under smaller layers and from an extrapolation of the line from 10 to more cm of lead to zero, we see that the increase of the hard component must be very small. Between 10 and 15 cm of lead the decrease is

¹⁾ W. HEITLER, The Quantum Theory of Radiation (1936).

²⁾ S. NEDDERMEYER and C. D. ANDERSON, Phys. Res., **51**, 884 (1937).

small on account of the effect of decay of mesons of lower energy (Fig. 3). So we decided to consider the difference between the number with no ab-

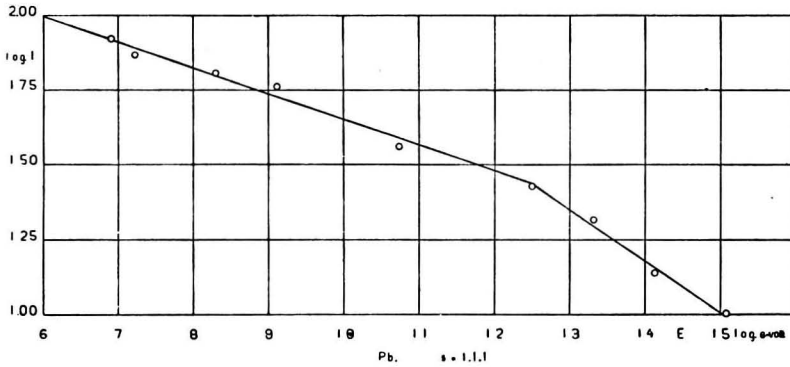


Fig. 2. Integral spectrum of the electron component found by absorption in lead.

sorption layer and the number under a layer of 10 cm Pb. as the number of the soft rays. Another supposition is made by extrapolation of the HEITLER

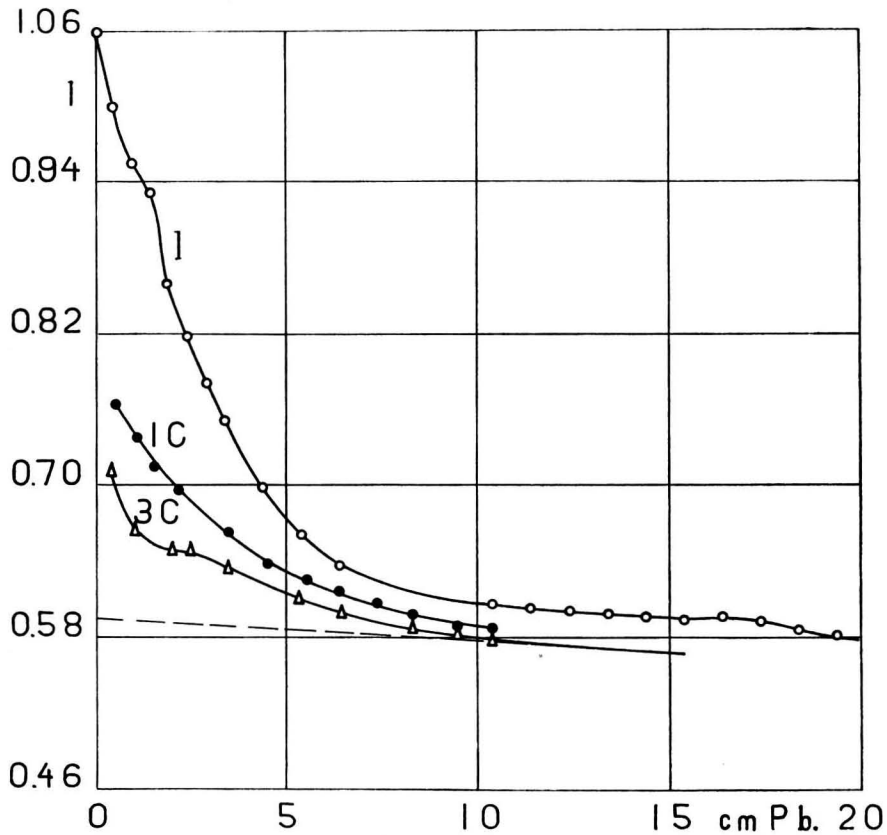


Fig. 3. Decrease of the intensity of Cosmic Radiation under layers of lead. I: ionisation chamber. 1C: number in one counter. 3C: coincidences in three counters.

formula above about 10^8 e-volt. We may fear that in this region the formula breaks down. For energies with a DE BROGLIE wavelength, small in relation to the dimensions of the electron, it will only be tentative. But at the moment we have no other way and for this reason we have made an extrapolation for higher energies. The value of the energy of an electron for a range of 10 cm Pb. is 10^{15} e-volt and the number with such energies and more will be very small. But from the phenomenon of the wide showers P. AUGER and his collaborators³⁾ and L. JANOSI & LOVELL⁴⁾ there are indications that such energies may occur. From the graph, which gives the relation between $\log. I$ and $\log. E$, we see that within the limits of uncertainty, the value of $\log. I$ is linear to $\log. E$, until a value of 5.10^{12} e-volt, according to a range of 8 cm in Pb. is reached. $S=1.11$. That means that the energy distribution is $N(E) = N_0 E^{-1.11}$. And up to the energy of 5.10^{12} e-volt we have 80 % of the electrons. For the remaining part $S=1.25$.

We can verify the value of S , because if we take another material we have to find the same value of S . For this reason we measured the decrease of the soft radiation in lighter materials as aluminium, paraffin, coal and water. But the difficulty is that we cannot bring enough material of this kind to stop the total soft radiation without making the distance between the counters too long and the cone in which we measure too small. In such a case the number of electrons would become too small to warrant a sufficient accuracy in a reasonable time. But there are more difficulties. At first we took paraffin as a suitable material to be placed between the counters and we could place a layer of 35 cm between the counters. We found that the absorption of paraffin is abnormally high in comparison with that of aluminium and later on the same was found in comparison with coal and with water, which were both normal in relation to aluminium and lead. But secondarily we found that coal gives an abnormally decrease for thicker layers, which can be explained by the production of secondary knockon electrons by mesons (fig. 4). It was found by SWANN and RAMSEY⁵⁾ that the production of one-electron showers by mesons increases on decrease of density of matter, which process is unexplained at the moment. But it is possible to find a regular decrease in water down to a layer of 60 cm of water and when we make a graph of $\log. I$ against $\log. E$, in which E means the energy, necessary for the ranges in water layers, we find again a linear relation within the limit of uncertainty of the measurements down to the value of 3.10^8 e-volt and with this value 40 % of the total number of electrons is stopped (fig. 5). When we calculated from this relation the value of $(S-1)$ we find 0.23 and for the differential spectrum $N(E) = N_0 E^{-1.23}$.

³⁾ P. AUGER, R. MAZE, P. EHRENFEST and A. FRÉON, J. de Physique, **10**, 1 (1939).

⁴⁾ L. JANOSI and LOVELL, Nature, **142**, 716 (1938).

⁵⁾ W. F. G. SWANN and W. E. RAMSEY, Phys. Res., **57**, 749 (1940).

We think that the difference with the distribution we found for Pb. is more than the limit of uncertainty. But we may be sure that the decrease of the number with energy is only a small fraction more than the inverse

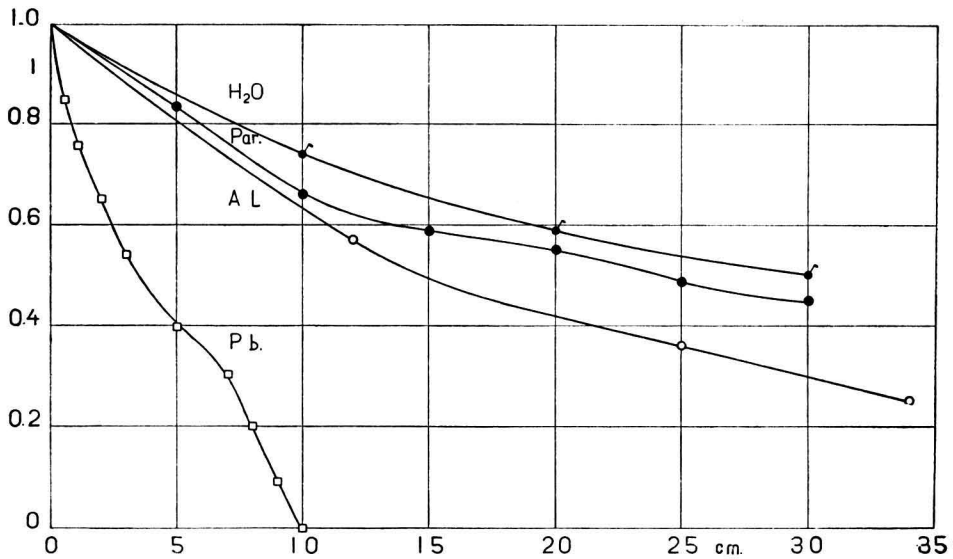


Fig. 4. Decrease of the electron component, produced in air, in H₂O, paraffin, Al and Pb.

of the energy, which means that it is much smaller than is accepted generally, vide identical with that of the spectrum of the mesons which goes down with the third power of E.

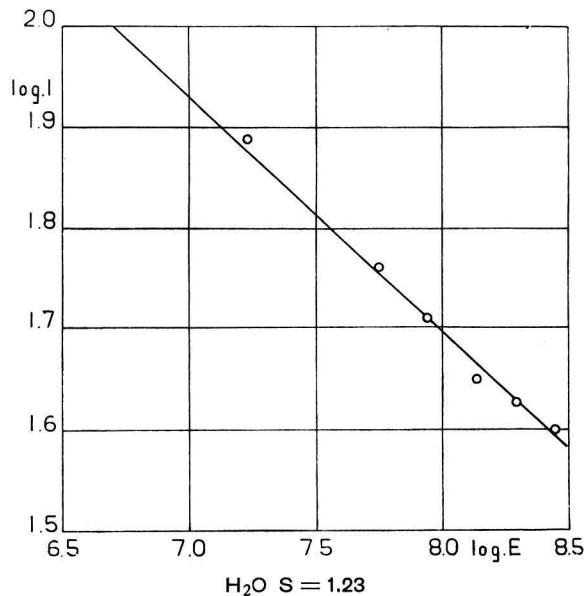


Fig. 5. Integral spectrum of the electron component found by absorption in water.

What the reason is for the abnormally high absorption in paraffin is not clear, especially because it is not found in coal and not in water, which have about the same number of protons p.c.c.

It is often found that under a thick layer of matter there is no Rossi-maximum of showers. Only JANOSI⁶⁾ reports he finds a soft shower-maximum under thick layers of material. In order to know the explanation the soft component was measured under thick layers of water (fig. 6),

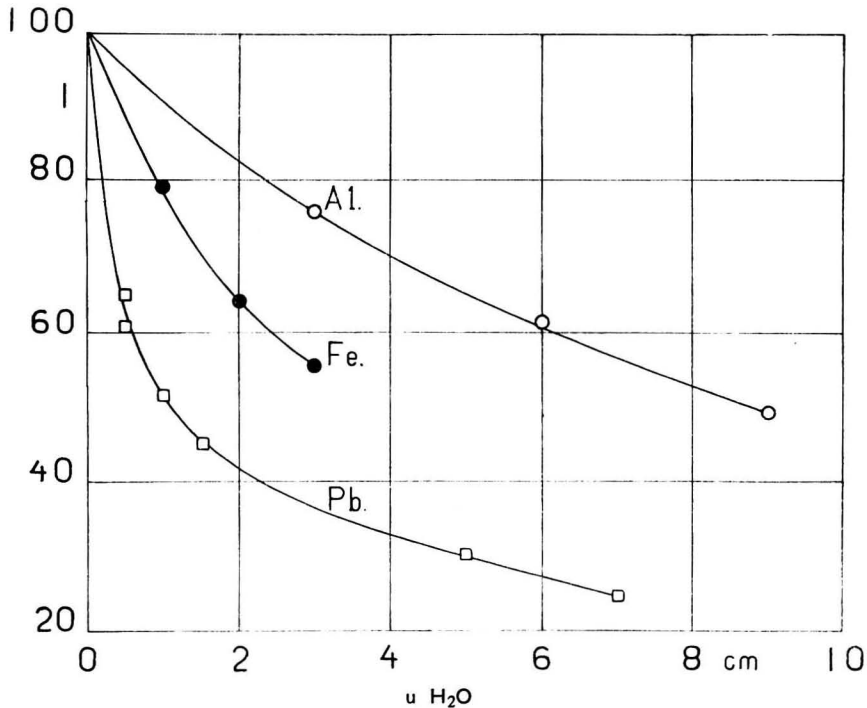


Fig. 6. Decrease of the electron component produced in water, in Al, Fe and Pb.

aluminium, iron and lead, and we found that the percentage of the soft radiation in relation to the hard component is under air 27 %, water 24 %, aluminium 20 %, iron 9.5 % and under lead 4.7 % (fig. 7), this is in agreement with the result of SWANN, mentioned above, that the number of soft secondaries in equilibrium with primaries in different material decreases with atomic number. We think that the real production in lead will not be smaller than it is in light material in a volume of the same number of electrons, but the loss of energy of the electrons necessary to escape from the volume element in which they are produced is larger, proportional to z^2 , and this will decrease their number and their energy. The number of the secondaries in relation to the hard primaries is given in graph 8. And the energyspectrum, at least for the lower spectral part, can be found from the relation $\log. I$ to $\log. E$ given in graph 9. We find that the

⁶⁾ L. JANOSI, Proc. Ray. Soc., A. 167, 499 (1938).

decrease is faster as the atomic number of the material of the layer is higher.

From each of these radiations the decrease is measured in different materials and we find that the energy of the electrons is smaller also with

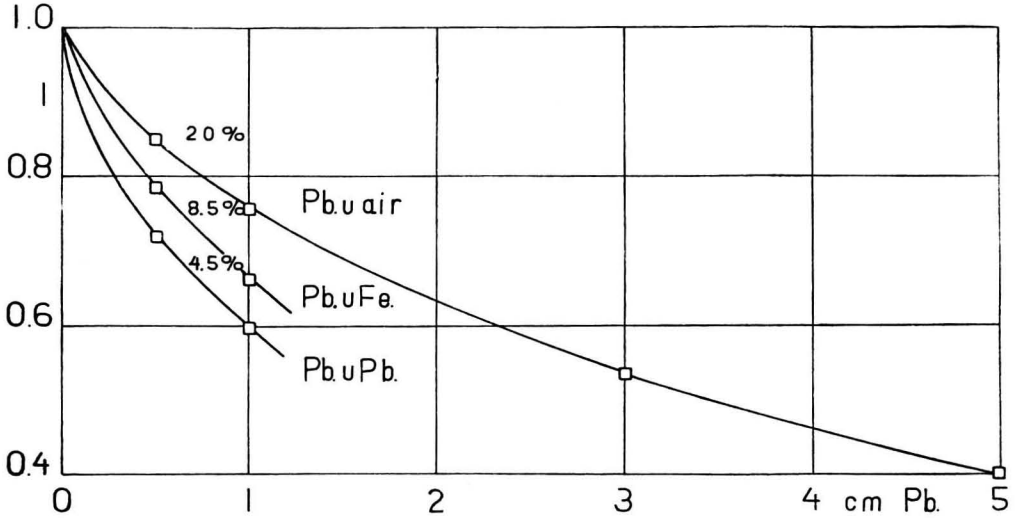


Fig. 7. Decrease in Pb of the electron component produced in air, Fe and Pb.

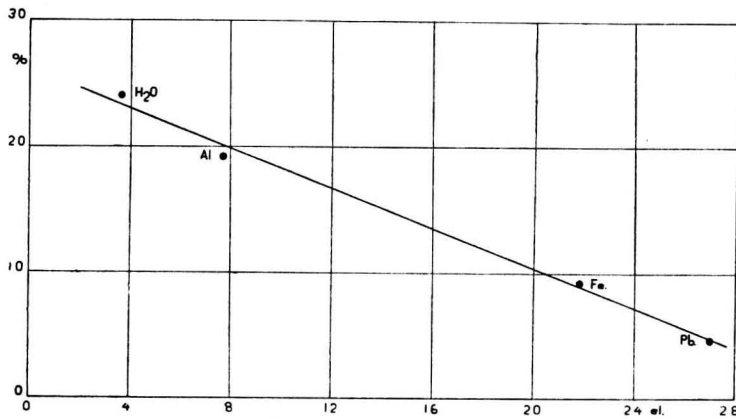


Fig. 8. Number of electrons found under H₂O, Al, Fe and Pb in relation to the number of mesons.

increasing atomic-number, in agreement with earlier experiments, when the absorption of single-electrons was measured ⁷⁾).

Graph 7 gives the result of this part of the experiments and their decrease was measured with smaller and wider opening-cones, 44° in one 100° in the other direction. One phenomenon is striking here: when we measure the number of electrons under lighter materials the production of electrons by the mesons in the absorbing layer overcompensates the

⁷⁾ J. CLAY, Physica, 3, 352 (1936).

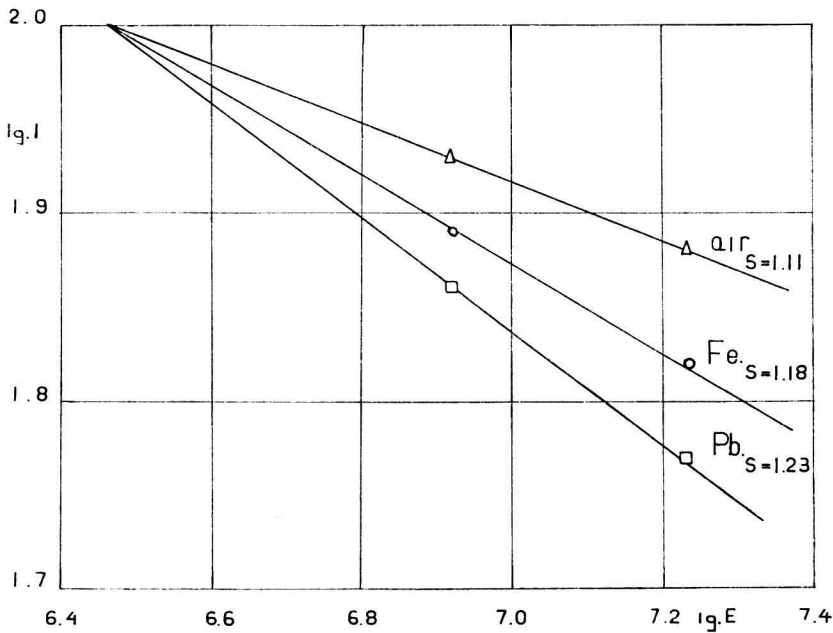


Fig. 9. Integral spectrum of electrons produced in air, Fe and Pb.

decrease. We see this in graph 10. The variation under absorbing paraffin, under Pb. and under Fe. and air. This now explains that the number of

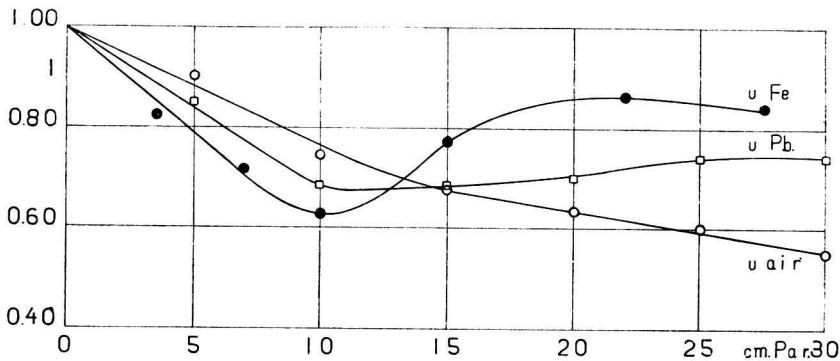


Fig. 10. Decrease of the electron component in paraffin. Produced in air, Fe and Pb.

electrons under thick layers of light matter can be restored so far, that enough electrons are present again to give a maximum in the showercurve.

In order to have a full picture of soft radiation it is necessary to know the angular distribution of it. This is partly — from $0-60^\circ$ — the same as that of the mesons ⁸⁾, $f(\theta) = 0.005 + 0.12 \cos^2 \theta$ p. cm² p. min., but for larger angles the percentage is larger and at a nearly horizontal direction it is 40 % of the total number instead of 20 %, as it is in the vertical.

⁸⁾ J. CLAY, J. T. WIERSMA and K. H. J. JONKER, Proc. Kon. Ned. Akad. v. Wetensch., Amsterdam, **41**, 706 (1938).