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The Absorption of Shower-Producing Cosmic Rays

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The coefficients of absorption of shower-producing cosmic rays have been measured in water, aluminum, iron and lead. The coefficients are nearly equal to 0.018 cm^{-1} times the densities. Showers from a lead scatterer were counted with three Geiger counters. A large block of aluminum was put above the scatterer to absorb the secondaries in the ordinary cosmic-ray beam and produce aluminum secondaries. An absorber which reduced the intensity of the primary rays was put above the aluminum block and its thickness was varied. The resulting variation of the number of showers gave the absorption of the primary rays producing the showers. Absorption coefficients have been obtained also for paraffin secondaries and for the tertiaries they produce in lead.

IT was shown in previous papers[1] that cosmic-ray showers are due to secondary rays in the ordinary cosmic-ray beam. The absorption coefficients of the secondary rays and the tertiary rays, or shower particles, were determined. The experiments described in the present paper were done with the object of measuring the absorption coefficients of the primary rays which produce the secondary and tertiary rays.

The apparatus used is shown in Fig. 1. The three circles represent Geiger counters and S is a lead plate. A large aluminum block was placed above the top counter as shown. The primary cosmic rays passing down through the aluminum block produce secondary rays. These secondaries produce showers of tertiary rays in the lead scatterer, S. The showers produce triple coincidences, in the three counters, which are recorded.

If a block of any material is placed above the aluminum block the number of showers recorded is reduced and so the absorption of the shower-producing primary rays in the material can be determined. It should be noted that the aluminum block must be thick enough to absorb the secondaries which accompany the primary rays and to replace them by aluminum secondaries. The aluminum block for this purpose was 13.0 cm thick, 30 cm long and 13 cm wide.

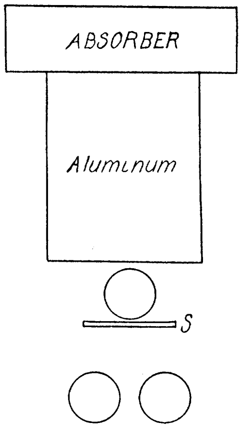

FIG. 1. Arrangement of apparatus.

The Geiger counters consisted of a copper cylinder 4.8 cm in diameter and 20 cm long, with a fine tungsten wire for the central electrode. These were sealed in glass tubes containing argon at about 3 cm Hg pressure. The upper counter was about 15 cm above the two lower ones which were 1.4 cm apart. The lead scatterer, S, was 0.85 cm thick, 10 cm wide and 30 cm long. The triple coincidences were recorded with the same amplifier used in the previous work.

The results obtained with an absorber of iron above the aluminum block are given in Table I.

TABLE I. *Observed and calculated number of coincidences with various thicknesses of iron absorber above the aluminum block.*

THICKNESS OF IRON ABSORBER	TOTAL NO. OF COINCIDENCES	TIME	COINCIDENCES PER HOUR	
			Obs.	Calc.
0 cm	256	8.7 hrs.	29.5	29.5
1.20	204	7.4	27.6	27.3
2.54	370	14.7	25.2	25.2
5.08	297	12.6	23.5	22.2
7.65	381	18.3	20.8	20.1
10.28	545	28.2	19.3	19.6
12.82	253	14.2	17.8	17.5
15.34	495	29.0	17.0	16.8
17.88	417	24.7	16.9	16.3

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[1] J. H. Sawyer, Phys. Rev. **44**, 241 (1933); **47**, 515 (1935); **47**, 635 (1935).

The iron absorber was 90 cm long, 25 cm wide and its thickness was varied.

The last column of Table I contains values of the expression $15+14.5e^{-0.137x}$ where x is the thickness of the iron absorber in cm. The constant, 15, is the triple coincidence counting rate when the lead scatterer, S, is removed. This corresponds to the usual "chance count." The calculated values agree with the observed numbers of coincidences per hour within the limits of error. The absorption coefficient of the primary rays is therefore approximately 0.137 cm^{-1} Fe.

Similar experiments have been done with water, lead and aluminum as absorbers. The water was in a tank 61 cm long and 42 cm wide. Its depth was varied from 0 to 115 cm. The lead absorber was 40 cm long, 18 cm wide and up to 11 cm thick. The aluminum absorber was 36 cm long, 13 cm wide and up to 9.5 cm thick. Table II gives the absorption coefficients found. The large block of aluminum, 30 cm long, 13 cm wide and 15.5 cm thick, was used in each case to absorb the secondaries in the ordinary cosmic ray beam and to produce aluminum secondaries.

TABLE II. *Absorption coefficients in various absorbers.*

ABSORBER	ABSORPTION COEFFICIENT	100 COEFFICIENT/ DENSITY
Water	0.0183 cm^{-1}	1.83
Aluminum	0.05*	1.9
Iron	0.137	1.74
Lead	0.197	1.74

* Owing to the small thickness of aluminum available for the absorber, this value is not as reliable as the others.

The last column of Table II gives the values of the absorption coefficients multiplied by 100 and divided by the densities. It appears that the coefficients are nearly proportional to the densities.

The absorption of the primary rays in lead was also measured using a large block of paraffin wax, 32×12×32.5 cm, in place of the aluminum block. The lead absorber was the same size as before and was varied from 0 to 11 cm thick. The absorption coefficient was found to be 0.175 cm^{-1} which is a little smaller than the value found with the aluminum block.

The absorption coefficients in lead of the secondary rays from paraffin and the tertiary rays these secondaries produce in lead were determined. This was done by varying the thickness of the lead scatterer, as in the experiments described in previous papers. The absorption coefficient of the paraffin secondaries was found to be 0.85 cm^{-1} Pb and that of the tertiaries to be 1.9 cm^{-1} Pb.

Table III gives the values of all the absorption coefficients found in this paper and in the previous papers.

TABLE III. *Absorption coefficients found in this and in previous papers.*

	PRIMARY RAYS PRODUCING SECONDARIES IN ALUMINUM				In paraffin
Absorber	H_2O	Al	Fe	Pb†	Pb
Coefficient (cm^{-1})	0.0183	0.05	0.137	0.197	0.175
Coefficient 100/Density	1.83	1.9	1.74	1.74	1.56
	SECONDARY RAYS				
Substance giving the rays	Air*	Air and Roof		Aluminum	Paraffin
Coefficient in lead (cm^{-1})	0.32	0.50		0.70	0.85
	TERTIARY RAYS FROM LEAD				
Substance giving the Secondary Rays	Air	Air and Roof		Aluminum	Paraffin
Coefficient in lead (cm^{-1})	1.18	2.58		2.0	1.9

* Values calculated from Rossi's (B. Rossi, Zeits. f. Physik **82**, 151 (1933)) and Funfer's (E. Funfer, Zeits. f. Physik *83*, 92 (1933)) results.
† The value, 0.5 cm^{-1} Pb, given previously (Phys. Rev. **47**, 635 (1935)) was wrong due to an arithmetical error.

The absorption coefficients of the primary shower-producing rays have been estimated previously by Johnson,[2] Montgomery[3] and Pickering.[4] They measured the number of showers at different altitudes or at different depths in water. The absorption coefficients they found are smaller than those found here, varying from 0.005 to 0.009 cm^{-1} H_2O. The difference may be due to the variation of the number of showers with the energy of the primaries. These and other writers have found that the number of showers increases with altitude much faster than the number of primary cosmic rays. This indicates a variation of the number of showers with the energy of the primaries, since the shape of the absorption curve for showers at any altitude is much the same.

I wish to thank Professor H. A. Wilson for many suggestions during the course of this work and for help in writing the paper.

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[2] Johnson, Phys. Rev. **40**, 638 (1932); **45**, 569 (1934).
[3] Montgomery, Phys. Rev. **47**, 339 (1935).
[4] Pickering, Phys. Rev. **47**, 423 (1935).