Some Recent Experiments on Cosmic Rays

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SEVERAL experiments on cosmic rays have been recently carried out in the Physical Laboratory of the University of Manchester. They were mainly concerned with the problem as to whether or not all the observed effects of cosmic rays can be accounted for by already known processes, or whether it is necessary to consider some new processes in connection with the cosmic-ray particles, or to postulate the existence of some new particles in the cosmic radiation.

We give here a preliminary account of the results so far obtained.

SHOWER PRODUCTION BY PENETRATING COSMIC RAYS (A. C. B. LOVELL)

The showers observed under thick screens are due to the penetrating component of cosmic rays. A theory developed by Bhabha suggests a probable mechanism, whereby a mesotron makes a direct collision with an electron, and the electron subsequently produces a cascade shower.

In order to investigate whether or not all the showers produced by the penetrating component could be accounted for by the above mechanism, 5200 photographs were taken by Lovell with a counter controlled cloud chamber, under 10, 20 or 30 cm lead. Fig. 1 shows the experimental arrangements used.

Altogether 463 showers of more than 5 particles were observed. For a comparison of the experimental results with the theory, a rigid selection of 32 showers was made, which all emerged from an area in the lead situated directly above the illuminated portion of the cloud chamber. Under these conditions one can safely assume that practically all the shower particles are detected by the cloud chamber. These selected showers can, therefore, be used to estimate the probability $P(N)$ of occurrence of showers with N particles as a function of N. Theoretically $P(N)$ can be calculated from Bhabha's formulae, by taking into account the actual intensity and energy spectrum of the mesotrons.

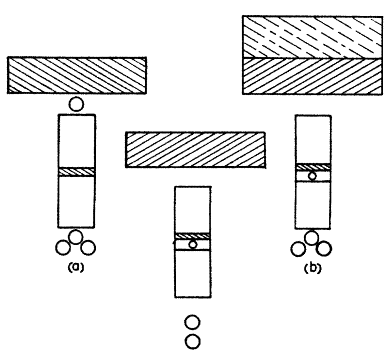


FIG. 1. Experimental arrangements.

The experimental and theoretical probabilities are compared in Fig. 2, from which it is seen that

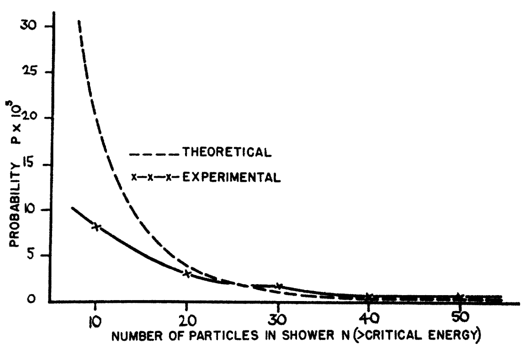


FIG. 2. Experimental and theoretical probabilities for production of knock-on showers by mesotrons.

the agreement is within the limit of uncertainty of the theory and the experiment. The divergence of the curves for small showers is due to the strong bias introduced by the counter system against recording them.

Some more conclusions can be deduced from the experiments referred to.

(a) It has been suggested that the mesotrons can give rise to showers of mesotrons in a single multiple process. Mesotrons could be distinguished from electrons in the above experiments, because they should traverse the 1.8-cm Pb plate across the chamber without giving rise to secondaries. Apart from two very doubtful cases, no shower of mesotrons has been detected in 463 electronic showers.

(b) A search for showers produced by non-ionizing particles other than photons has been made in the photographs taken with the arrangements (b) and (c) Fig. 1. In those arrangements one counter was placed inside the chamber under the lead plate and the other counters were below the chamber. It was possible in this way to detect showers generated in the lead plate by non-ionizing rays. Out of the 200 showers which were obtained, 120 were ordinary cascade showers started in the lead above the chamber, and 60 were showers generated by mesotrons in the plate across the chamber, probably by knock-on processes. In the remaining 20 cases a shower emerged from the plate and no ionizing particle was visible in the upper part of the chamber. These showers could not be due to photons, since it is extremely unlikely that a photon emerges from the lead above the chamber unaccompanied by electrons. They could, however, be cases of oblique knock-on showers, in which the mesotron track was not photographed. In fact, all of them were found to originate from the edge of the illuminated part of the chamber.

(c) A similar investigation for the production of single ionizing particles was made with arrangement (c). 500 traversals of the lead plate by single mesotrons were observed, but no single ionizing particles were seen to start from the plate.

In conclusion it may be said that the above experiments give no evidence that processes other than cascade showers occur, or that any non-ionizing particles other than photons are present in the cosmic radiation.

Origin of the Ionization Bursts (J. G. Wilson and A. C. B. Lovell)

Some features of the transition curve for ionization bursts are difficult to account for on the assumption that the bursts are due to cascade showers initiated by single particles. The difficulties would disappear, to some extent, if one would assume that the ionization bursts observed under a screen are due to many electrons and photons hitting the screen simultaneously. If so, the ionization bursts should be associated with big air showers.

In order to test this hypothesis, Wilson and Lovell carried out the following experiment. Two cloud chambers were arranged one above the other, 100 cm apart, having between them a screen of 36 cm of Al. Both chambers were controlled by a counter set arranged so as to detect showers emerging from the screen.

So far, five big showers have been observed in the bottom chamber. The density of particles was large enough (>20 per 100 cm^2) to produce a quite large ionization burst in an ionization chamber of ordinary size. In all these cases many particles were also visible in the upper chamber, as expected.

Figure 3 shows one of the 5 pairs of photographs obtained. Comparing the density of the tracks in the two chambers, one must keep in mind that the upper chamber is nearly twice as deep as the bottom one.

Absorption of Penetrating Cosmic-Ray Particles in Gold (J. G. Wilson)

Some new experimental results on the energy loss of mesotrons have been obtained by Wilson. The measurements were taken in a cloud chamber across which was placed a 2-cm gold plate.

In the energy range between 2×10^8 and 7×10^8 ev the measured energy loss agrees closely with the theoretical energy loss due to ionization (see Table I). (The theoretical energy loss was calculated from the Bloch formula, on the assumption that the mass of mesotrons is 200 times the electronic mass.)

For energies larger than 7×10^8 ev the ionization loss is hardly detectable, and actually most of the tracks do not show any change of curvature larger than the experimental errors. However, 9 particles—7 percent of all the observed penetrating particles—were found to suffer a large energy loss. All these particles have an initial

Table I. *Energy loss in gold.*

Energy Range (ev)	Energy Loss (ev) Theoretical	Experimental
$2\times10^8<E<4\times10^8$	13.2×10^6	$(12.1\pm2.0)\times10^6$
$4\times10^8<E<7\times10^8$	14.0×10^6	$(14.3\pm3.6)\times10^6$

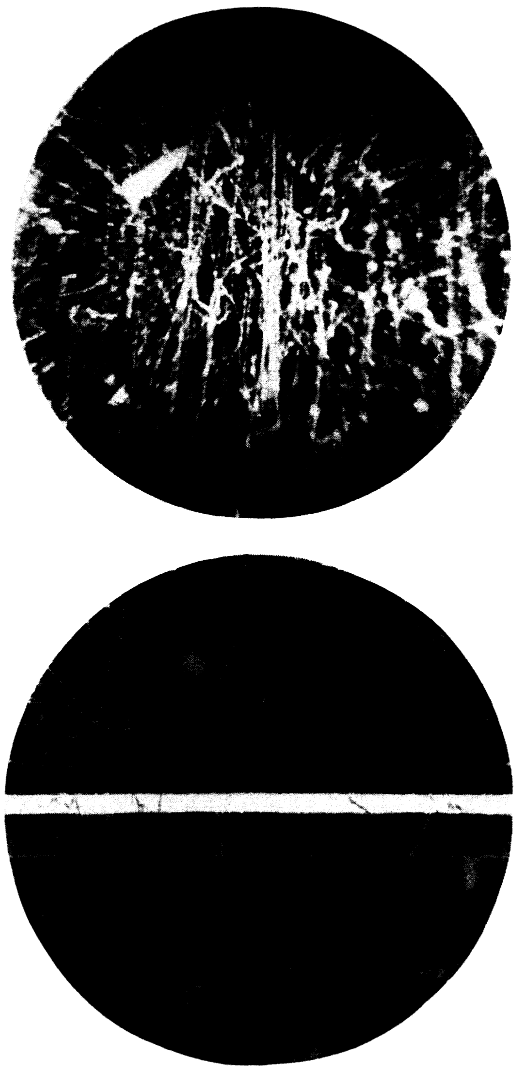


FIG. 3. One of five large showers observed in two chambers. Upper chamber, area 200 cm^2, is placed 100 cm above the lower chamber, area 96 cm^2, with a 2-cm Pb plate at the center. An aluminum plate 36 cm thick separates them.

energy less than 2×10^9 ev. All but one of these particles are positive, and the curvature change of the single negative particle, which is comparatively small, may be due to distortions.

The observed absorbable particles cannot be electrons, since for an incident electron of energy between 7×10^8 and 2×10^9 ev the presence of a single particle below 2 cm of gold is very improbable. They could be mesotrons undergoing some rare absorption process, or they could be particles of another kind which are more absorbable than mesotrons. It is, perhaps, not unlikely that they are protons stopping in the gold plate and generating mesotrons which appear under the plate.

Especially interesting are two cases of low energy mesotrons. Both of these show the increased energy loss anticipated for mesotrons. Moreover, from the actual energy loss it is possible to calculate the mass and this turns out to be about 170 times the electronic mass.

THE NON-IONIZING COMPONENT OF COSMIC RADIATION (B. ROSSI AND L. JÁNOSSY)

The non-ionizing component of cosmic radiation was investigated by Rossi and Jánossy with the arrangement schematically shown in Fig. 4. The 5 counters A and, similarly, the 2 counters D were connected in parallel. Threefold coincidences B, C, D, and fourfold coincidences A, B, C, D were recorded simultaneously. The difference between these is the number of threefold coincidences which are not accompanied by a fourfold coincidence, i.e., the number of *anticoincidences*.

Counters A covered the whole solid angle subtended by counters B, C, D. Therefore, each single ionizing particle coming from above the apparatus and hitting B, C, D, must hit A as well. Only ionizing particles produced by a non-ionizing agent between A and B can traverse B, C, D without traversing A, thus giving rise to anticoincidences.

The photon component of cosmic radiation was first investigated.

The *transition curve* for showers produced by photons was measured by counting anticoincidences with lead screens of different thickness between A and B (position s_1) and with no lead in the other position. The experimental results are compared in Fig. 5 with the theoretical transition curve calculated according to the cascade theory (solid curve). A small zero effect, due mainly to showers coming from the side, has been subtracted from the observed rates. The theoretical calculations have been carried out assuming a γ-ray spectrum $f(E) = \text{const.}\ (1/E)$ for $E<E_c$ and $f(E) = \text{const.}\ (E_c^2/E^3)$ for $E>E_c$ as predicted by the cascade theory. ($E_c = 1.5\times10^8$ ev is the critical energy in air.) The agreement is as good as can be expected.

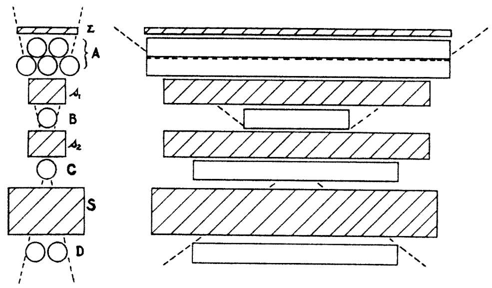


FIG. 4. Arrangement to investigate non-ionizing rays.

The *absorption* curve of photons was measured by counting anticoincidences with 2 cm lead in s_1 and with lead screens of different thickness above the counters A (position Σ). The results are given on a logarithmic scale in Fig. 6.

The interpretation is as follows. A photon hitting the screen Σ can: (a) traverse the screen unaffected, (b) produce a Compton electron or an electron pair. In case (a) the position is exactly the same as if the absorber Σ had not been there at all, and the chance of recording the photon by means of an anticoincidence is the same as it was without the absorber. In case (b), however, a shower has already started in the screen Σ, and it is very improbable that the counters B, C, D are discharged without one of the counters A being discharged as well.

Thus the decrease of the number of anticoincidences due to Σ is a direct measure for the probability that a photon is removed by pair production or Compton scattering.

The experimental points lie, within the statistical fluctuations, on a straight line. This is exactly the expected result, both because the absorption coefficient of high energetic photons varies slowly with the energy, and because most of the observed anticoincidences are due to a rather narrow band of the γ-spectrum. Moreover, the numerical agreement with the theory of γ-ray absorption is very satisfactory. This is shown in Fig. 6, where the dotted line represents the absorption curve calculated according to Bethe and Heitler's formula, and the full line is the least squares fitting of the experimental results.

Measurements were then made to investigate whether ***penetrating ionizing particles*** were produced by some non-ionizing agent. To this purpose a screen of 10 cm Pb was put permanently between C and D (position S) and 5 cm Pb were changed from position s_1 to position s_2. Table II gives the experimental results.

The small difference found in the number of anticoincidences seems to indicate that in 5 cm lead some ionizing penetrating particles are actually produced by non-ionizing rays. Control experiments are, however, necessary in order to ascertain the real meaning of this difference.

Table II shows further that the difference in the total number of threefold coincidences is larger than the difference in the number of anticoincidences (1.5 percent instead of 0.2 percent). It is, therefore, clear that only a minor part of the effect for threefold coincidences can be accounted for by the production of penetrating particles in the absorber. The major part of it is probably due to the scattering of mesotrons in the lead.

Most likely, some disturbing phenomena of a similar kind are responsible for similar effects previously found by several authors.

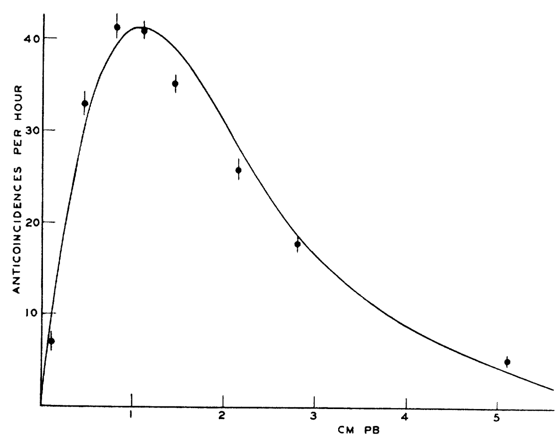


FIG. 5. Transition curve of showers produced by photons.

TABLE II. *Test for production of penetrating ionizing particles.*

	Position s_1 (per hour)	Position s_2 (per hour)	Difference (per hour)	Difference in percent of the threefold coinc.
Threefold coincidences B, C, D	328 ± 1.1	323 ± 1.1	5 ± 1.5	(1.5 ± 0.45)
Anticoincidences	3.6 ± 0.12	2.97 ± 0.11	$0.63+0.16$	$(0.2+0.05)$

THE SECOND MAXIMUM OF THE TRANSITION CURVE FOR SHOWERS (B. ROSSI AND L. JÁNOSSY)

Several authors have reported observations indicating that the shower transition curve in lead shows, after the first maximum, at about 1.5 cm, a second maximum at between 15 and 20 cm. The results of various observers, however, are not in agreement. Since great importance is attached to the occurrence of a second maximum from the theoretical point of view, Rossi and Jânossy repeated the experiments with several different geometrical arrangements and greater accuracy.

The results were entirely negative. For example, with an arrangement more sensitive to wide spread showers they found a decrease of (4±1.5) percent from 9 to 17 cm Pb. With another arrangement, more sensitive to small angle showers and the same thickness of lead, the difference was (0±3) percent.

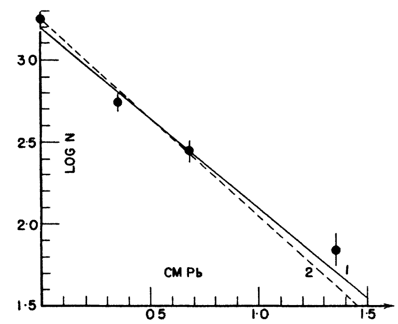


FIG. 6. Absorption curve of cosmic γ-rays. (1) observed with $s_1=2.0$ cm Pb. (2) calculated.

DISCUSSION

J. Clay, *Amsterdam:* In relation to the results of Professor Rossi, I might add that Mr. V. Gemert and I measured the decrease of radiation in three different directions, 0°, 60° and 75° from the vertical, with a threefold coincidence apparatus with an opening cone of 16°. The distance of the outer counters was 125 cm, and 100 cm of lead could be put between the counters and more was still above the counters so that the opening cone was filled up. The values for 60° were measured with two different instruments (see Fig. 1).

The number of the vertical coincidences was mostly 10,000; so that the uncertainty is 1 percent: for the other directions 1500 (uncertainty±2 percent). From the graph (Fig. 1) we see that the decrease is very different for rays from different directions, and we may remark that a calculation by Dr. Bruins of the decay of the mesotrons agrees perfectly with the observed values for 0° and 60° when we take the value of 20 km for the layer of formation, an original energy distribution proportional to $E^{-2.93}$, and a lifetime between 1.7 and 2×10^{-6}. The agreement with the observed values in the direction of 75° is not yet satisfactory.

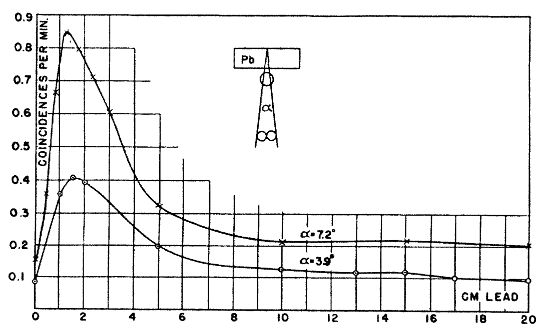
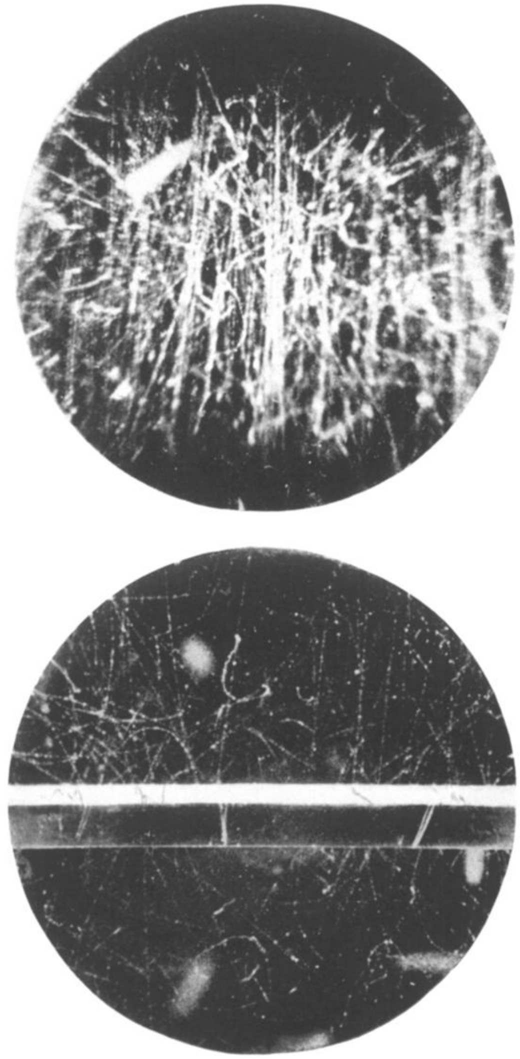


FIG. 1. Radiation at 0°, 60°, and 75° from the vertical with varying amounts of lead between the three counters.

We may remark here that we find a difference of the barometric coefficient in different directions. For the 75° direction it is more than twice that for the vertical. At present we are not able to find an explanation for it. The difference could be possibly explained if we supposed that mesotrons of higher energy were created at higher levels than those of lower energy. It may be observed from the graph that the amount of secondaries is the same in vertical and 60° directions but is more in the 75° direction. In both cases with the greater inclination the secondaries are less penetrating.



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