EVIDENCE FOR THE EXISTENCE OF NEW UNSTABLE ELEMENTARY PARTICLES

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AMONG some fifty counter-controlled cloud-chamber photographs of penetrating showers which we have obtained during the past year as part of an investigation of the nature of penetrating particles occurring in cosmic ray showers under lead, there are two photographs containing forked tracks of a very striking character. These photographs have been selected from five thousand photographs taken in an effective time of operation of 1,500 hours. On the basis of the analysis given below we believe that one of the forked tracks, shown in Fig. 1 (tracks *a* and *b*), represents the spontaneous transformation in the gas of the chamber of a new type of uncharged elementary particle into lighter charged particles, and that the other, shown in Fig. 2 (tracks *a* and *b*), represents similarly the transformation of a new type of charged particle into two light particles, one of which is charged and the other uncharged.

The experimental data for the two forks are given in Table 1; H is the value of the magnetic field, α the angle between the tracks, p and Δp the measured momentum and the estimated error. The signs of the particles are given in the last column of the table, a plus sign indicating that the particle is positive if moving down in the chamber. Careful re-projection of the stereoscopic photographs has shown that each pair of tracks is copunctal. Moreover, both tracks occur in the middle of the chamber in a region of uniform illumination, the presence of background fog surrounding the tracks indicating good condensation conditions.

Though the two forks differ in many important respects, they have at least two essential features in common: first, each consists of a two-pronged fork with the apex in the gas; and secondly, in neither case is there any sign of a track due to a third ionizing particle. Further, very few events at all similar to these forks have been observed in the 3-cm. lead plate, whereas if the forks were due to any type of collision process one would have expected several hundred times as many as in the gas. This argument indicates, therefore, that the tracks cannot be due to a collision process but must be due to some type of spontaneous process for which the probability depends on the distance travelled and not on the amount of matter traversed.

Table 1. Experimental data

Photograph	H (gauss)	α (deg.)	Track	p (eV./c.)	Δp (eV./c.)	Sign
1	3500	66·6	*a* *b*	$3{\cdot}4 \times 10^8$ $3{\cdot}5 \times 10^8$	$1{\cdot}0 \times 10^8$ $1{\cdot}5 \times 10^8$	+ −
2	7200	161·1	*a* *b*	$6{\cdot}0 \times 10^8$ $7{\cdot}7 \times 10^8$	$3{\cdot}0 \times 10^8$ $1{\cdot}0 \times 10^8$	+ +

This conclusion can be supported by detailed arguments. For example, if either forked track were due to the deflexion of a charged particle by collision with a nucleus, the transfer of momentum would be so large as to produce an easily visible recoil track. Then, again, the attempt to account for Fig. 2 by a collision process meets with the difficulty that the incident particle is deflected through 19° in a single collision in the gas and only 2·4° in traversing 3 cm. of lead—a most unlikely event. One specific collision process, that of electron pair production by a high-energy photon in the field of the nucleus, can be excluded on two grounds: the observed angle between the tracks would only be a fraction of a degree, for example, 0·1° for Fig. 1, and a large amount of electronic component should have accompanied the photon, as in each case a lead plate is close above the fork.

We conclude, therefore, that the two forked tracks do not represent collision processes, but do represent spontaneous transformations. They represent a type of process with which we are already familiar in the decay of the meson into an electron and an assumed neutrino, and the presumed decay of the heavy meson recently discovered by Lattes, Occhialini and Powell[1].

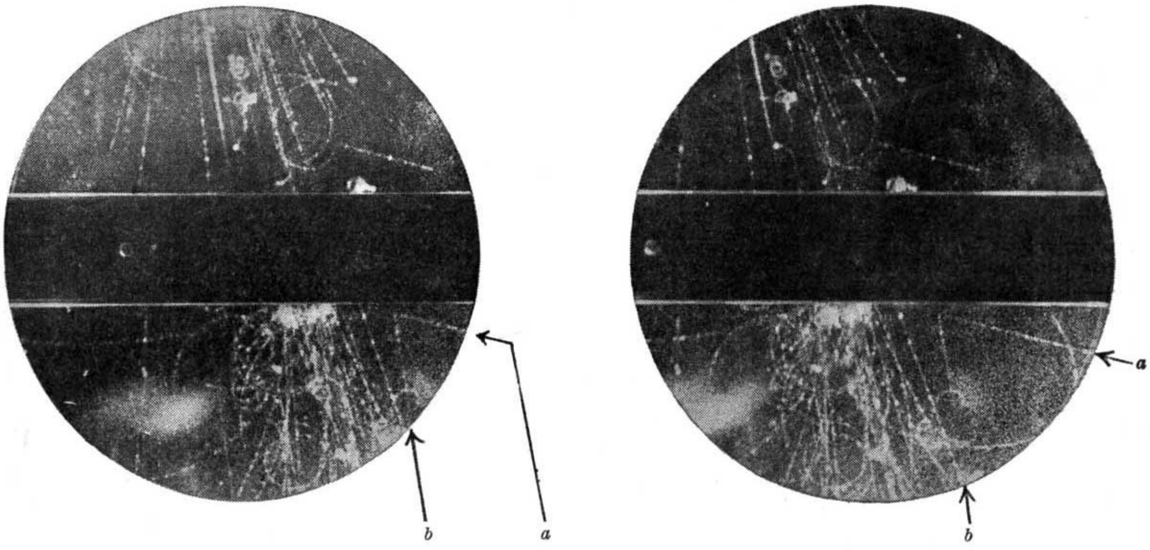

Fig. 1. Stereoscopic photographs showing an unusual fork (*a b*) in the gas. The direction of the magnetic field is such that a positive particle coming downwards is deviated in an anticlockwise direction

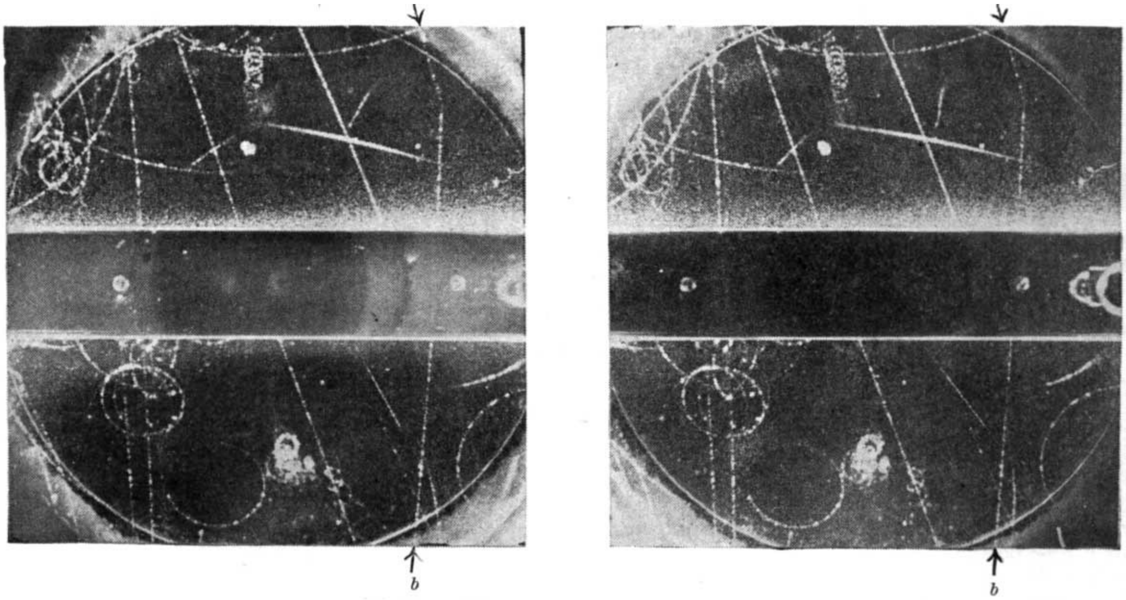

Fig. 2. STEREOSCOPIC PHOTOGRAPHS SHOWING AN UNUSUAL FORK (*a b*). THE DIRECTION OF THE MAGNETIC FIELD IS SUCH THAT A POSITIVE PARTICLE COMING DOWNWARDS IS DEVIATED IN A CLOCKWISE DIRECTION

The Masses of the Incident Particles

Let us assume that a particle of mass M and initial momentum P is transformed spontaneously into two particles of masses m_1 and m_2, momenta p_1 and p_2 at angles of θ and φ with the direction of the incident particle. Then the following relations must hold :

$$\sqrt{M^2c^4+P^2c^2} = \sqrt{m_1^2c^4+p_1^2c^2} + \sqrt{m_2^2c^4+p_2^2c^2} \quad (1)$$

$$P = p_1 \cos\theta + p_2 \cos\varphi \quad (2)$$

$$p_1 \sin\theta = p_2 \sin\varphi. \quad (3)$$

These general relations may be used to obtain the mass of the incident particle as a function of the assumed masses of the secondary particles.

The value of M must be greater than that obtained by taking the rest masses of the secondary particles as small compared with their momenta ; thus the minimum value $M_{\min}$ is given by the following equation :

$$M_{\min}c^2 = c\sqrt{(p_1+p_2)^2 - P^2}. \quad (4)$$

Applying this equation to the forked track of Fig. 1, after calculating P from the observed values of p_1 and p_2, it is found that $M_{\min}$ is $(770 \pm 200)m$, where m is the mass of the electron. The application of equation (4) to the forked track of Fig. 2, however, after calculating p_2 from the observed values of P and p_1, shows that $M_{\min} = (1{,}700 \pm 150)m$. This value of the mass would require an ionization for the incident particle of twice minimum, which is inconsistent with the observed ionization. We are therefore justified in assuming that the real value of P is greater than the observed value which, as indicated in Table 1, has a large error. If larger values of P are assumed, then $M_{\min}$ is reduced in value. The lowest value of $M_{\min}$ is $(980 \pm 150)m$ if P is $14 \cdot 5 \times 10^8$ eV./c. Beyond this value of P the mass increases slowly with increasing momentum. No choice of incident momentum will bring the mass of the incident particle below 980 m.

In the special case where the incident particle disintegrates transversely into two particles of equal mass m_0, giving a symmetrical fork, equation (1) reduces to the following expression,

$$\frac{M}{m} = \frac{2m_0}{m}\left(1 + \frac{p^2c^2}{m_0^2c^4} \cdot \sin^2\theta\right)^{1/2}, \quad (5)$$

where p is the momentum of each of the secondary particles. Some typical results for different assumed secondary particles, calculated from equation (5), are given in Table 2. On the reasonable assumption that the secondary particles are light or heavy mesons, that is, with masses of $200m$ or $400m$, we find that the incident particle in each photograph has a mass of the order of $1{,}000m$.

TABLE 2. MASS OF INCIDENT PARTICLE AS A FUNCTION OF MASS OF SECONDARY PARTICLE

Photograph	Assumed secondary particle m_0/m	Momentum of observed secondary particle (eV./c.)	Incident particle M/m
1	0	$3 \cdot 5 \times 10^8 \pm 1 \cdot 0 \times 10^8$	770 ± 200
	200	,,	870 ± 200
	400	,,	1110 ± 150
	1837	,,	3750 ± 50
2	0	$7 \cdot 7 \times 10^8 \pm 1 \cdot 0 \times 10^8$	980 ± 150
	200	,,	1080 ± 100
	400	,,	1280 ± 100
	1837	,,	3820 ± 50

Upper values of the masses of the incident particles may also be obtained from the values of the ionization and the momenta. Thus for each of the observed particles in Fig. 1, the ionization is indistinguishable from that of a very fast particle. We conclude, therefore, that $\beta = v/c \gg 0 \cdot 7$. Since the momentum of the incident particle may be found from the observed momenta of the secondary particles, we can apply equation (1) to calculate M. In this way we find $M/m \ll 1{,}600$. Again, since the ionization of the incident particle in Fig. 2 is light, $\beta \gg 0 \cdot 7$, from which it can be shown that $M/m \ll 1200$. This last result, however, must be taken with caution because of the uncertainty in the measured value of the momentum of the incident particle.

One further general comment may be made. This is that the observation of two spontaneous disintegrations in such a small number of penetrating showers suggests that the life-time of the unstable particles is much less than the life-time of the ordinary meson. An approximate value of this life-time may be derived as follows. The probability of an unstable particle of life-time τ_0 decaying in a short distance D is given by

$$p = \frac{D(1 - \beta^2)^{1/2}}{\tau_0 \, c \, \beta}. \qquad (6)$$

Since the total number of penetrating particles in the penetrating showers so far observed is certainly less than 50, we must assume that the number of our new unstable particles is unlikely to have been greater than 50. Since one particle of each type has been observed to decay, we can therefore put $p \approx 0{\cdot}02$. Setting $D \approx 30$ cm., and $\beta = 0{\cdot}7$, we find from equation (6) that $\tau_0 = 5\ 0 \times 10^{-8}$ sec.

We shall now discuss possible alternative explanations of the two forks.

Photograph 1. We must examine the alternative possibility of Photograph 1 representing the spontaneous disintegration of a charged particle, coming up from below the chamber, into a charged and an uncharged particle. If we apply the argument which led to equation (4) to this process, it is readily seen that the incident particle would have a minimum mass of 1,280m. Thus the photograph cannot be explained by the decay of a back-scattered ordinary meson. Bearing in mind the general direction of the other particles in the shower, it is thought that assumption of the disintegration of a neutral particle moving downwards into a pair of particles of about equal mass is more probable. Further, it can be stated with some confidence that the observed ionizing particles are unlikely to be protons because the ionization of a proton of momentum $3{\cdot}5 \times 10^8$ eV./c. would be more than four times the observed ionization.

Photograph 2. In this case we must examine the possibility of the photograph representing the spontaneous decay of a neutral particle coming from the right-hand side of the chamber into two charged particles. The result of applying equation (4) to this process is to show that the minimum mass of the neutral particle would be about 3,000m. In view of the fact that the direction of the neutral particle would have to be very different from the direction of the main part of the shower, it is thought that the original assumption of the decay of a charged particle into a charged penetrating particle and an assumed neutral particle is the more probable.

We conclude from all the evidence that Photograph 1 represents the decay of a neutral particle, the mass of which is unlikely to be less than 770m or greater than 1,600m, into the two observed charged particles. Similarly, Photograph 2 represents the disintegration of a charged particle of mass greater than 980m and less than that of a proton into an observed penetrating particle and a neutral particle. It may be noted that no neutral particle of mass 1,000m has yet been observed; a charged particle of mass 990m ± 12 per cent has, however, been observed by Leprince-Ringuet and L'héritier[2].

Peculiar cloud-chamber photographs taken by Jánossy, Rochester and Broadbent[3] and by Daudin[4] may be other examples of Photograph 2.

It is a pleasure to record our thanks to Prof. P. M. S. Blackett for the keen interest he has taken in this investigation and for the benefit of numerous stimulating discussions. We also wish to acknowledge the help given us by Prof. L. Rosenfeld, Mr. J. Hamilton and Mr. H. Y. Tzu of the Department of Theoretical Physics, University of Manchester. We are indebted to Mr. S. K. Runcorn for his assistance in running the cloud chamber in the early stages of the work.

[1] Lattes, C. M. G., Occhialini, G. P. S., and Powell, C. F., *Nature*, **160**, 453, 486 (1947).

[2] Leprince-Ringuet, L., and L'héritier, M., *J. Phys. Radium.* (Sér. 8), 7, 66, 69 (1946). Bethe, H. A., *Phys. Rev.*, **70**, 821 (1946).

[3] Jánossy, L., Rochester, G. D., and Broadbent, D., *Nature*, **155**,1 42 (1945). (Fig. 2. Track at lower left-hand side of the photograph.)

[4] Daudin, J., *Annales de Physique*, 11e Série, **19** (Avril–Juin), 1944 (Planche IV, Cliché 16).

THE GRASSHOPPER PROBLEM IN NORTH AMERICA

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OFFICIAL figures compiled by the Division of Grasshopper Control of the United States Bureau of Entomology show that in the ten-year period 1936–46, crops to the value of 424,563,614 dollars were destroyed by grasshoppers, and 26,088,211 dollars was spent on control measures. No similar statistics are available for Canada, where the general situation with regard to grasshoppers is similar. The annual figures for the same period show considerable fluctuation, apparently dependent on natural variations in grasshopper populations; but they do not suggest any general downward trend which might be interpreted as a cumulative result of persistent artificial control measures. It must be stressed that these measures are unquestionably very successful so far as the protection of standing crops of the year is concerned, and the organisation of control, based on close co-operation of Federal and State agencies and the farmers, leaves little to be desired. Both the organisation and the technique of artificial control are being continually perfected, and it is estimated that, on the average, each dollar spent on grasshopper control serves to save crops to the value of 35 dollars. This is a remarkable achievement, and a large share of credit for it belongs to the Division of Grasshopper Control, admirably organised and run by Dr. Claude Wakeland and his staff. Nevertheless, it is clear that the protection of crops by direct control methods cannot be relaxed, and efforts on an ever-increasing scale will have to continue indefinitely. The policy of direct control is a palliative which cannot lead towards a lasting solution of the grasshopper problem in the North American continent.

This state of affairs has been realized by entomologists of the United States and Canada for some time, and their views were forcibly expressed in the following resolution adopted at a session of the Committee on Grasshopper Research at Lincoln, Nebraska, in 1946: "Millions of dollars have been appropriated and spent during the past twenty years by state, provincial, federal and dominion agencies for materials and labour for the applied control of grasshoppers. During the same period, the amount of money spent on research for a solution of the grasshopper problem has been woefully inadequate.