PROCEEDINGS OF THE ROYAL SOCIETY A
MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

# On the Technique of the Counter Controlled Cloud Chamber

P. M. S. Blackett

*Proc. R. Soc. Lond. A* 1934 **146**, doi: 10.1098/rspa.1934.0154,
published 1 September 1934

# On the Technique of the Counter Controlled Cloud Chamber

By P. M. S. Blackett, F.R.S.

(Received May 18, 1934)

[Plates 2 and 3]

## 1—General Considerations

The method by which very fast atomic particles are made to take their own cloud photographs has proved very useful for the investigation of cosmic rays. A short account of the method and a detailed account of the results obtained by its use have already been given by Blackett and Occhialini.*

Recently Locher† and also Anderson, Millikan, Neddermeyer, and Pickering‡ have used the same method and have obtained some beautiful results.

The method consists in using two or more tube counters to detect the passage of a high energy particle through a cloud chamber. The electrical response of the counters is then made to actuate the cloud chamber by means of relays. In order that the cloud tracks so formed should be fairly fine, it is necessary that supersaturation of the vapour should be attained very quickly after the passage of the ray.

Now when a fast particle traverses a gas, it produces an equal number of positive and negative ions within a narrow cylindrical column. Neglecting, at present, recombination and the effect of the electric field, these ions will diffuse away from their starting-point according to the diffusion equation, so that after a time $\tau$ their distribution will be given by§

$$n = \frac{N_0}{4\pi D\tau} e^{-\frac{r^2}{4D\tau}}, \tag{1}$$

where $N_0$ is the total number of ions of both signs per cm of track and D is the diffusion coefficient of the ions. If at a time $\tau$ after the passage of the ray the supersaturation of the vapour reaches the critical value for condensation on the ions, the mobility of the ions will then be suddenly reduced nearly to zero. So a photograph of such a track, taken a short time after the attainment

* 'Nature,' vol. 130, p. 363 (1932); 'Proc. Roy. Soc.,' A, vol. 139, p. 699 (1933).

† 'Phys. Rev.,' vol. 44, p. 779 (1933); 'Phys. Rev.,' vol. 45, p. 979 (1932).

‡ 'Phys. Rev.,' vol. 45, p. 357 (1934).

§ Jaffé, 'Ann. Physik,' vol. 42, p. 303 (1913).

of supersaturation, will give the projection on, say, the $zx$ plane of the instantaneous position of the ions at time $\tau$. The number of ion images in a strip parallel to OZ and of width $\delta x$ is

$$\frac{N_0}{4\pi D\tau}\,\delta x\int_{-\infty}^{+\infty} e^{-\frac{x^2+y^2}{4D\tau}}\,dy,$$

so the superficial density of the ion images $\rho(x) = dn/dx$, at a distance $x$ from the centre of the image on the photographic plate, is given by

$$\rho(x) = \frac{N_0}{\sqrt{4\pi D\tau}}\,e^{-\frac{x^2}{4D\tau}}, \tag{1}$$

or

$$\rho(x) = \rho_0\,e^{-\frac{x^2}{4D\tau}}, \tag{1A}$$

where

$$\rho_0 = \frac{N_0}{\sqrt{4\pi D\tau}}.$$

It is convenient to define what may be called the 90% breadth $X_1$, as that width of the image which contains 90% of the ion images. This is found to be given by

$$X_1 = 4\cdot 68\sqrt{D\tau}. \tag{2}$$

Since the mean value of D for the positive and negative ions* in air at N.T.P. is $0\cdot 034$ cm$^2$ sec$^{-1}$, we have $X_1 = 0\cdot 86\sqrt{\tau}$ cm at N.T.P. So if we demand that the tracks shall not be more than 1 mm broad, then we must have $\tau$ not more than 1/70 second.

We can reasonably allow half this time for the release and half for the fall of the piston. If the piston has to move 1 cm in 1/140 sec, then it will require an acceleration of about 50 g, where g is the acceleration of gravity. Since the necessary acceleration $a$ for the piston to move a given distance in a time $\tau$ is proportional $1/\tau^2$, and since from (2), $\tau \propto X^2$, we have a $\propto 1/x^4$. So to obtain tracks $\frac{1}{2}$ mm broad, one would need an acceleration of 800 g.

From the same considerations it follows that for a given force applied to the piston, the breadth of the tracks is proportional to the fourth root of the mass of the piston.

It is clearly of importance to make the distance the piston has to move as small as possible. For a given initial height of chamber this distance depends on the expansion ratio required, and this depends on the gas and on the vapour used. We have so far used air and water, which require an expansion ratio

* Thomson, "Conduction of Electricity through Gases," vol. 1, p. 77 (1928).

of about 1·30. But by using a monatomic* gas, say, argon, in conjunction with a vapour such as alcohol, the necessary expansion will be about 1·12. This will allow still finer tracks to be obtained, or alternatively a larger and deeper chamber could be made to give the same breadth of track.

Since the diffusion coefficient D is inversely proportional to the pressure, the breadth of the tracks will be inversely proportional to the square root of the pressure of the gas.

## 2—*The Movement of the Piston*

There are two main ways of making the piston move. In the first, to which the calculation made above is relevant, the force is applied to the piston previously to the arrival of the ray. The piston is kept from moving by a catch, which is then released when the ray arrives. Now a piston of, say, 13 cm diameter, which is sufficiently rigid for this method to be used, could hardly be made lighter than 1 or 2 kg. Thus to give an acceleration of 50 g a force of 50 to 100 kg is required. It is not quite easy to release such a force by a catch in 1/150 second.

The alternative method is to apply the force only after the ray has arrived, and the simplest method† of doing this is to apply the force by a sudden alteration of the pressure on the two sides of the piston as in C. T. R. Wilson's original technique. With this method a very much lighter piston can be used. Since now the force on the piston increases with the time, its displacement will vary approximately as $t^3$, and so the breadth of a track will vary roughly as the sixth root of the mass of the piston.

Since a cloud chamber for use with cosmic rays must be placed in a vertical plane, the liquid seal method of C. T. R. Wilson cannot be used. Hence the piston must be kept tight either by means of oil lubrication between accurately machined surfaces, as was used by Auger‡ and others, by the use of oil lubricated piston rings of some kind, or by the use of a flexible material, such as rubber or thin metal.

Preliminary experiments were made with the first method, but it was found that it was difficult to keep such a ground piston tight except by using an oil of such viscosity that the viscous forces made the expansion rather slow.

* Locher (*loc. cit.*) has recently used argon and water vapour in a tube-controlled cloud chamber.

† Various explosion methods have been considered but none actually tried.

‡ 'Ann. Physique,' vol. 6, p. 184 (1926).

Suppose that the clearance between piston and cylinder is about 25 $\mu$, then at a mean velocity of 150 cm per sec the viscous force on a piston whose cylindrical surface has an area of 300 sq cm and is lubricated by, say, Hyvak pump oil with a viscosity of 10 c.g.s. units in about 180 kg.

The breaking force of a lubricated leather piston ring would certainly be smaller than this, but we doubted whether it would be really tight and therefore did not try it. The new type of chamber using a fixed gauge as the floor of the chamber, recently described by C. T. R. Wilson,* is clearly very suitable for use with the tube controlled method.

## 3—*The Design of the Chamber*

These various considerations led us therefore to design the chamber shown in fig. 1. The piston, A, was made of aluminium alloy† and together with the hollow piston rod of monel metal weighed only 280 gm. The chamber was made tight by means of the flexible diaphragm B, made of reinforced rubber 1 mm thick. The chamber was usually filled with oxygen at a pressure of about 1·7 atmospheres. The space under the piston which can be closed by a light valve E, is filled with air, before the expansion, to the same pressure as in the chamber. The amount of the expansion is governed by the position of the nut H on the piston rod.

The expansion is made by moving a trigger F holding the valve closed (see also fig. 2). The valve weighs about 20 gm and has an area of 5·3 sq cm. The pressure on it is 0·7 atmosphere so that when released it starts to move with an acceleration of 160 g.

The dead space under the piston is made as small as possible, so that little more air shall have to flow out of the valve than is made necessary by the movement of the piston.

An oscillograph record of the movement of the piston is shown in fig. 18, Plate 3. From this it will be seen that the piston takes 0·005 second to travel its full movement of 1 cm that it then bounces a little and finally comes to rest 0.008 second after the start. Its maximum velocity is about 280 cm per sec, and its initial acceleration is about 80 g.

The quick deceleration of a piston moving with this velocity requires careful consideration. The method adopted was the simplest possible one, that of

* 'Proc. Roy. Soc.,' A, vol. 142, p. 88 (1933).

† A bare aluminium surface has a detrimental effect on the track formation. So the piston was covered with black enamel.

allowing the piston to fall flat with most of its area on to the thin rubber sheet G, which covers the floor of the casting. By this means the piston is brought to rest within less than a millimetre, with not much bounce, and without danger of the distortion that might be introduced by applying the braking force at the rim or at the centre alone. The measured deceleration of the piston at

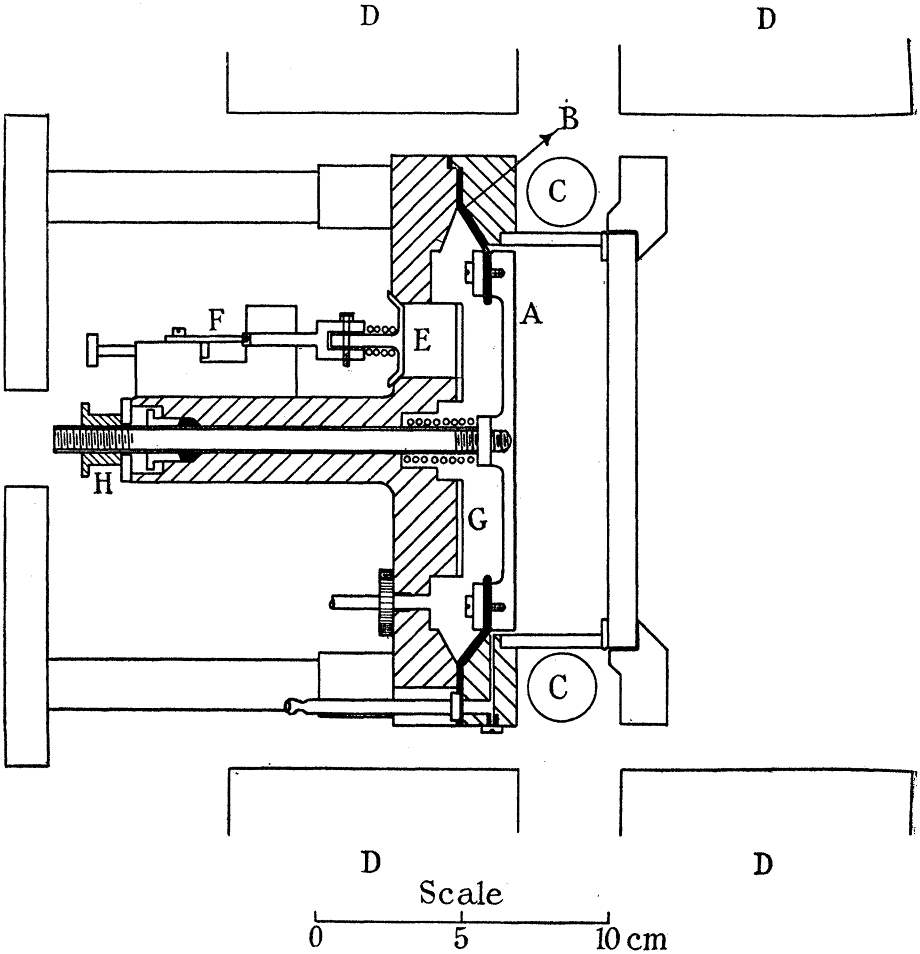



FIG. 1

the bottom of its movement is about 400 g. The piston bounces about $\frac{1}{2}$ mm which corresponds to a momentary 3% reduction in the expansion ratio.

The bounce is much more marked if a heavier piston is used. For instance, a brass piston, three times as heavy, bounced about 1·5 mm; that is, three times as much as the aluminium one.

The Geiger counters C were placed in such a position that any ray passing straight through both must also go through the illuminated part of the chamber. The whole chamber is placed inside a water cooled solenoid D.

The electric field used was usually about 3 volt per cm. Taking the mean mobility* at N.T.P. as about 1·6 cm/sec/volt/cm, we find that the separation of the positive and negative ions is not large enough to make the track double.

### 4—*The Release Mechanism*

Fig. 2 shows the method of releasing the valve. A continuous current passes through the small electro-magnet G and is of just sufficient magnitude to keep a light armature H attracted to it against a spring J. The electrical impulse from the amplifier connected to the Geiger counters is fed to the grid of a thyratron. When the latter flashes over, it short circuits the small magnet and allows the armature to fly off. The movement of the armature is transmitted by the nut K to the arm M and so to the long wire L, which is already under tension due to the spring N. A small clearance P is provided between the nut and the arm. Without such a clearance the adjustments are very critical and the mechanism therefore uncertain in action. In the arrangements used a movement of the armature of less than $\frac{1}{2}$ mm is sufficient to release the valve.

The method of adjustment is as follows. The two springs N and J are tightened till the catch F is just not released and the armature H just does not leave the magnet. Then the nut K is screwed up till it just does not touch the bar M.

The magnet and its circuit must be designed to make the time from the flashing over of the thyratron to the instant when the valve is released as small as possible.

The circuit used is shown in fig. 3. If the thyratron flashes over at $t = 0$, the current $i$ in the magnet falls from its initial value $i_0 = \mathrm{V}/(\mathrm{R} + \mathrm{G})$ to its final value $i_1 = \mathrm{VS}/\mathrm{R}'(\mathrm{S} + \mathrm{G})$, where $\mathrm{R}' = \mathrm{R} + \mathrm{SG}/(\mathrm{S} + \mathrm{G})$. The time constant T of the decay, before the armature releases, is L/R′.

To get a large change in the current through the magnet we must have $\mathrm{R} \gg \mathrm{S}$; the value of S is of the order of 20 ohms. Then G must be chosen to limit the current through the thyratron to a safe value. We made F and G both about 600 $w$.

* Dee, 'Proc. Roy. Soc.,' A, vol. 116, p. 664 (1927.)

In order to make T small, it is necessary to make the magnet small with only a few turns, and to use large external resistances.

A consideration of the acceleration of the armature on release also leads to the result that the magnet must be made as small as possible. For the

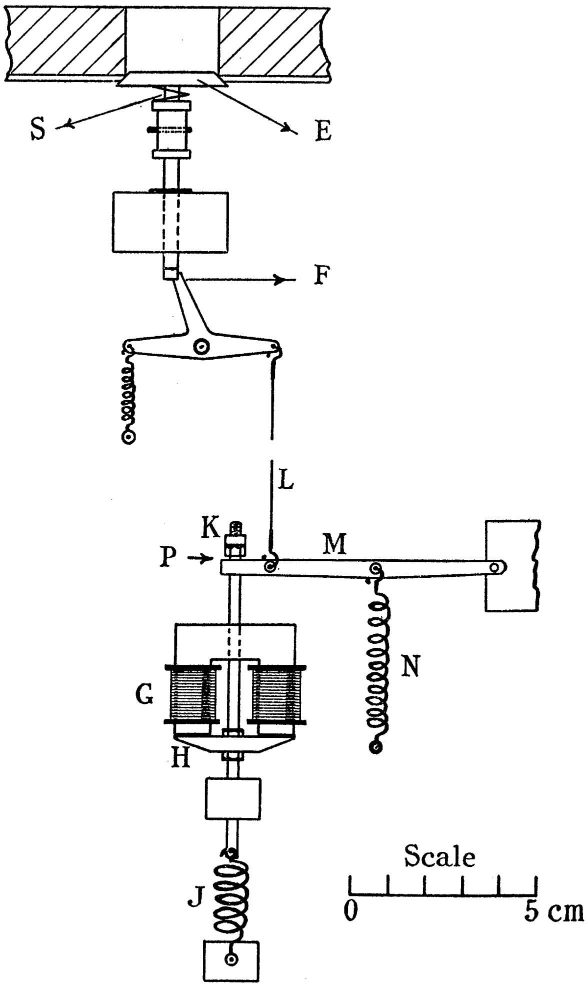



Fig. 2

mechanical force exerted by the magnet on the armature is proportional to the square of the linear dimensions of the magnet, while the mass of the armature is proportional to the cube, so the acceleration at release is inversely proportional to the linear dimensions.

The laminated magnet used, fig. 3, has 250 turns and a cross-section of 1 sq cm. Its calculated inductance is about 0·1 Henries. Since R′ ≑ 600 *w*, the time constant of the circuit T ≑ 2 × $10^{-4}$ seconds.

The armature system had a mass of about 15 gm and the measured pull off force for a current of 0·18 amps was about 3 kg. So an acceleration of the order of 200 g was obtained.

In the construction of such magnets it is very important that the air gap between the armature and the magnet shall be as small as possible, in order to get the greatest possible attractive force.

The whole apparatus was tested by measuring the time from the flashing over of the thyratron to the end of the expansion. This was found to be very nearly 0·010 second. The measurement of the separation of the positive and negative ions of a cosmic ray track, gave a similar value.

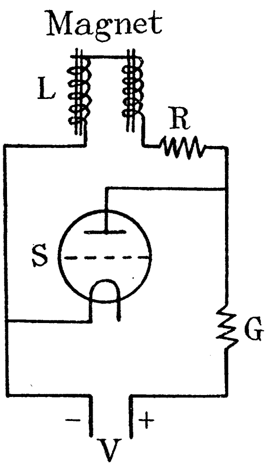


FIG. 3

### 5—*The Illuminating System*

We used the following method of illumination. A capillary mercury lamp was connected directly to the secondary of an 8000 volt transformer connected to the 220 volt mains. To make the flash a large current, 100 to 200 amps, was passed through the primary for 1/50 to 1/20 second. If an A.C. supply is used, the flash is, of course, intermittent. If a D.C. supply is used, the flash is continuous. The illumination from such a lamp is adequate to allow the photography of single droplets from a direction at right angles to the direction of illumination.

### 6—*The Distortion of the Tracks*

One of the chief difficulties of this tube-controlled method is the distortion of the tracks; that is, the final photograph does not represent accurately the original path of the ionizing ray.

(*a*) In the first place, since the ray goes through the chamber before the expansion, the whole original track is subjected to a simple *strain* by the expansion. Actually, of course, owing to the effect of the walls, etc., the distortion is more complicated than this.

But in addition to this distortion, which occurs *before* the drops are formed at the end of the expansion, there is the distortion which occurs between this instant and the time when the photograph is taken. There are three main types of this to be considered.

(*b*) The tracks are distorted by the fall of the drops through the gas. This velocity of fall is approximately *uniform*, and is of the order of $\frac{1}{2}$ cm per second, depending on the size of the drops and so on the expansion ratio and the density of ionization. Owing to this motion it is never possible to photograph later than about $\frac{1}{4}$ second after the expansion without distortion.

(*c*) After the expansion, the gas near the walls warms up first so that convection currents develop, consisting most obviously in the rapid fall of the central mass of cold gas. This motion is much greater in a vertical than in a horizontal chamber. If it be assumed that the displacement *forces*, causing this motion, increase linearly with the time from the moment of expansion, then the displacement of a drop due to this cause, will vary* as $t^3$.

It is a consequence of this rapid increase of distortion with the time that it is necessary, when using a vertical chamber, to take the photograph very soon after the end of the expansion. More illumination is therefore required, since the drops have not grown to their full size in so short a time.

(*d*) There is a type of distortion which may be called accidental, in contrast to the two former types, and which has caused us considerable trouble. The gas appears sometimes to be subject to a local swirling movement. Marked evidence of this is seen in some of the photographs already published. It is difficult to be quite sure of the cause of this gas motion, but we believe that it is due partly to the electric wind produced by the electrification of hairs, or possibly of the rubber diaphragm. A hair on the piston, for instance, which touches the walls of the chamber during the expansion, may become electrified by friction, and produce a sufficient electric wind to cause serious distortion. Confirmation of this view is obtained from the observation that large numbers of condensation nuclei are often found associated with the swirls. Also the swirling is absent when a slow expansion is made.

It is possible that our chamber is particularly liable to this trouble owing to some fault in the design.

The best way of avoiding errors of measurement arising from distortions (*b*), (*c*), and (*d*) is to start the illumination before the start of growth of the drops.† In this way any distortion, except that of type (*a*), can be noticed. Anderson uses this method.

* Assuming that viscous damping is not important.

† Anderson and others, *loc. cit.*

### 7—*The Magnetic Field*

The solenoid used had an internal diameter of 23 cm and consisted of four sectional coils in series, each with 100 turns of copper tube of 7·7 cm external diameter and 4·7 mm bore. The total resistance was 0·34 *w* and the weight of copper was 120 kg. A current of 200 amps was generally used giving 80,000 ampere turns and a field of 2200 gauss at the centre, with a power expenditure of 7 kw. Water was passed through the coils at the rate of 5 litres a minute (the water connections being in parallel), but this flow only sufficed to keep the steady temperature down to about 70° C. Sometimes 300 amps was used, but the current could then only be run for 2 minutes at a stretch.

Since the average time of waiting for a cosmic ray to arrive was 2 minutes, it was not possible conveniently to obtain more than 2200 gauss over the chamber. And since the electric power required varies as the square of the magnetic field, there was no possibility of obtaining, continuously, any great increase of field by using a solenoid of this type, except by the use of very large powers. A new chamber has therefore been made to fit between the poles of a large electro-magnet. With this new arrangement a field of 10,000 gauss could be obtained continuously with the same power required to produce 2000 gauss with the solenoid.

It is of interest to compare these figures with those given by Anderson* for the performance of the magnet used in his experiments. He used 440 kw. of power and a water flow of 160 litres per minute to obtain a field of 15,000 gauss. The ratio $H/\sqrt{W}$ is then nearly the same for Anderson's and our solenoid.

### 8—*A Cloud Chamber between the Poles of an Electro-magnet*

Through the kindness of the Director of the National Physical Laboratory, an old Poulsen arc electro-magnet, weighing about 5000 kg was lent to the Cavendish Laboratory. This produced a field of nearly 10,000 gauss near the pole face with a gap of 12 cm when using about 100,000 ampere turns. The power consumed was about 6 kw.

The chamber shown in fig. 4 was very like the one already described except for the modification necessary to allow it to go between the pole pieces. The whole object of the design was to reduce, as far as possible, the gap between the

* 'Phys. Rev.,' vol. 44, p. 406 (1933).

pole pieces. For, provided the iron is not nearly saturated, the field obtained is inversely proportional to this gap.

As no piston rod could conveniently be used, the piston A was unsupported except by the rubber diaphragm which served to close the chamber. When in the upper position, the piston rested against three brass stops B. When in the expanded position it lay flat on a rubber covered iron plate C. The expansion

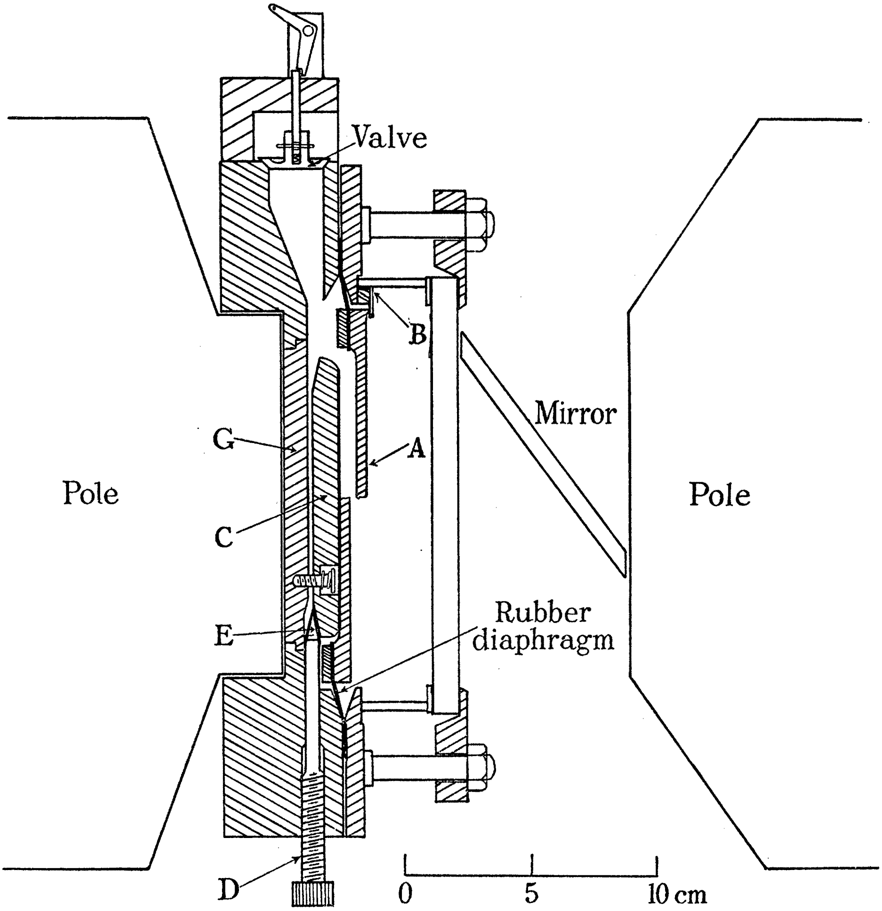



Fig. 4

was changed by altering the position of this iron plate. This was done by means of three long screws, D, with coned ends, E, on which the iron plate rested. The main casting was of brass, but an iron plate G was let into the back so as to form a continuation of the pole piece. Since the top of the iron plate, C, was effectively the pole face, this device enabled the tracks to be photographed within less than a centimetre of the pole face.

The tracks were photographed by two cameras, using a mirror at an angle of about 45°.

The chamber was made originally with two valves placed symmetrically so as to ensure that no large pressure differences developed over the surface of the piston, which would cause it to twist during the expansion. However, one valve proved adequate, presumably owing to the fact that, since the inertia of the air under the piston is very small compared with the inertia of the piston itself, the pressure is equalized underneath the piston before it has twisted appreciably. The release mechanism was identical in principle with that already described.

Many hundreds of photographs have been taken with this apparatus. One is reproduced in fig. 12, Plate 2.

## 9—*The Breadth of the Tracks*

Equation (2) gives what has been called the 90% breadth $X_1$ of the tracks. Below are given the observed and calculated values of $X_1$, for tracks in $O_2$ and $H_2$ at a mean pressure of 1·5 atmospheres, when the delay $\tau = 0{\cdot}01$ second.*

| Gas. | $\overline{D}$ NTP. | $\overline{D}$ at 1·48 atmos. | X cals. mm. | X obs. mm. |
|---|---|---|---|---|
| $O_2$ | 0·032 | 0.022 | 0·71 | 0·85 |
| $H_2$ | 0·135 | 0·092 | 1·42 | 1·78 |

It is difficult to measure $X_1$ at all precisely, but the estimated values given are in rough agreement with the theoretical calculations. Figs. 10*a*, 10*b*, Plate 2, show typical electron tracks in oxygen and hydrogen.

Now these measurements were made on fast electron tracks where the number $N_0$ of ions per cm is of the order of 100. When, however, the particle producing the track is an alpha-particle, or a still more heavily charged particle, $N_0$ may have a value of the order of $10^5$. With such large values of $N_0$, certain other considerations affect the observed breadth of the tracks.

Firstly, a considerable recombination of the positive and negative ions will take place. From Diebner's† measurements, one finds that in our apparatus about half the ions produced by an alpha-particle will disappear by recombination. Jaffe‡ has discussed the question theoretically, and has shown that,

* Thomson, *loc. cit.* D assumed inversely proportional to pressure.

† 'Z. Physik,' vol. 10, p. 247 (1931).

‡ 'Ann. Physik,' vol. 42, p. 303 (1913).

even though recombination is taking place, the distribution remains a Gaussian one, though $N_0$ no longer remains constant but decreases with the time according to the relation

$$N_0' = \frac{N_0}{1 + \frac{\alpha N_0}{4\pi D} \log\left(\frac{4D\tau}{b^2} + 1\right)},$$

where $\alpha$ is the coefficient of recombination, and $b^2$ is a constant measuring the initial distribution of ions at the time of their formation, and has a value $3 \times 10^{-6}$ for air.

The photographic negative of such a heavily ionized track will show a central black part bordered by edges showing a rapid decrease of drop density. The larger the photographic exposure the broader the black part of the track will appear, since the individual drop images will be larger and will therefore the sooner run together, to form a completely black image. Now we find experimentally that with our particular optical arrangement a superficial drop density of about 1000 drops per sq cm gives a practically black image. Hence we can define the photographic breadth $X_p$ of a track, as its breadth up to points where $\rho$ reaches the value 1000 drops per sq cm.

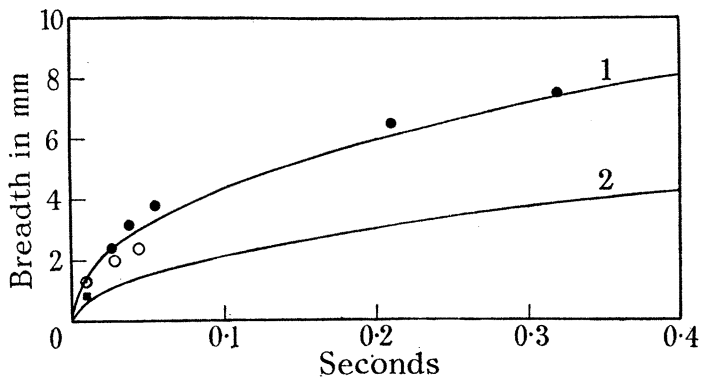



FIG. 5—Breadth of tracks in oxygen at 1·5 atmospheres for different times T of formation. Curve 1, $X_p$ equation (3); 2, $X_1$ equation (2); ● $\alpha$ particles, $X_p$, ○ protons, $X_p$; ■ electrons $X_1$.

Denoting this value by $\rho_1$, we find from (1) and (2) that

$$X_p = 4\cdot 0\,(D\tau \log \rho_0/\rho_1)^{\frac{1}{2}}. \quad (3)$$

This equation can be tested by measuring the photographic breadth of those alpha-ray tracks for which the positive and negative ions are separated. For the time $\tau$ can be calculated from this separation. The curve (*a*) in fig. 5

shows the calculated value of $X_p$ plotted against $\tau$, for an alpha-particle,* for which $N_0' = 4 \times 10^4$. The points represent the results of measurements on tracks. The agreement is very satisfactory, considering that the conception of a photographic breadth is only a rough one, and the measured value will depend on the strength of the light and many other factors.

Curve (*b*) shows how the 90% breadth $X_1$, calculated from (2), varies with $\tau$.

### 10—*On the Interpretation of some very Broad Tracks*

In several of our original series of photographs described in our former paper were found tracks nearly a centimetre broad, such as those reproduced in figs. 8, 14, 15, 16, 17, Plate 2; 19, and 21 Plate 3. These were provisionally attributed to alpha-particles from radio active contamination, which passed through the chamber as much as half a second before the expansion. However, this interpretation presented certain difficulties and the question was left open till a full investigation could be made of the question of the track breadths. Later on, the view was put forward† that such tracks were probably not due to contamination, but might be interpreted as recoil tracks set in motion by the collision of neutrons associated with the cosmic ray showers. This view is almost certainly false, for the calculations of the breadths that have been given above show that such broad tracks as these must, in fact, be due to particles which have passed through the chamber a long time before the expansion, and cannot possibly be explained, as was thought at that time, as due to particles of very great ionizing power passing through at the same time as the cosmic rays, which actuated the counters.

For the number of ions per cm of path due to various types of recoil nuceli can be calculated from the data of Blackett and Lees.‡ It is found, for instance, that a nitrogen nucleus produces about $2 \times 10^5$ ion pairs per cm in air over the last half-centimetre of its range. Similarly an argon recoil nucleus ionizes at about the same rate over the last 3 mm of its range.

If we calculate from (3) the value of $X_p$ for $N_0 = 2 \times 10^5$ and $\tau = 0 \cdot 01$ second, we find a value about $1 \cdot 9$ mm. Again, if $N_0$ is given the very high value of $10^7$, even then $X_p$ only has the value $2 \cdot 2$ cm. It is therefore quite

* The mean value for $N_0$ for an alpha particle from RaC in air at N.T.P. is 68,000. Taking recombination into account and allowing for the higher pressure in the chamber we get a value about 40,000.

† Solway Conference, Brussells, October, 1933.

‡ 'Proc. Roy. Soc.,' A, vol. 134, p. 658 (1932).

impossible to attribute a track 1 cm broad to a particle passing 0·01 second before the expansion. The correct interpretation is almost certainly that which attributes the broad tracks to particles of much lower ionizing power passing a much longer time before the expansion.

A confirmation of this view may be obtained as follows. A few of the broad tracks photographed are so good technically that it is possible to count the distribution of drops on the edges of the track. In this way a partial test of the theoretical distribution can be made and the unknown constants $\tau$ and $N_0$ can be obtained directly. One of these tracks is shown in fig. 16, Plate 2, and also very much enlarged in fig. 17, Plate 2.

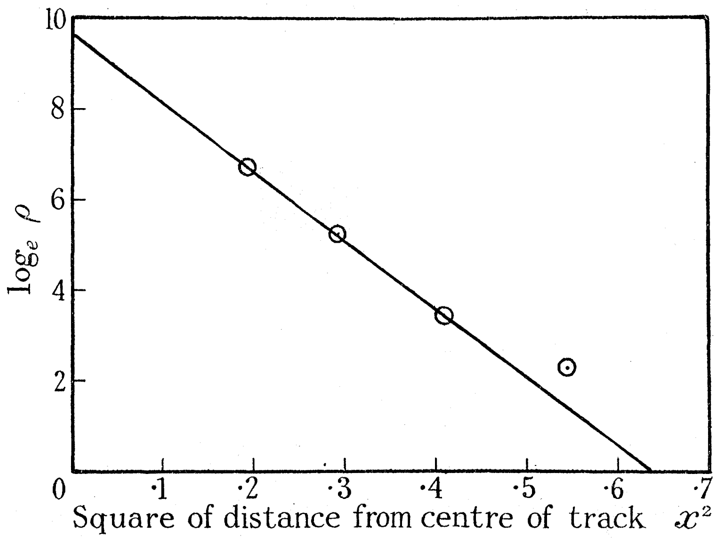



FIG. 6—Observed distribution of drops at edge of the track shown in figs. 16 and 17 Plate 2.

In fig. 6 is shown the observed distribution. The curve shows that the relation between log $\rho$ and $x^2$ is linear, as it should be from (1A). The constants are found to be $N_0' = 6700$ and $\tau = 0\cdot78$ seconds. Since the separation of the positive and negative ions for such a long delay is complete, the photograph shows those of one sign only,* so the figure obtained above must be compared with an expected value of about 15,000. The discrepancy is not very serious since the method is rough and gives directly log N and not N. Several other tracks give comparable values of $N_0$ and $\tau$.

* The reason why a very broad track is usually single and not double is merely that the positive and negative ion tracks are seldon both in the illuminated part of the chamber.

It can therefore be taken as certain that these very broad tracks have nothing directly to do with the cosmic rays actuating the counters.

If these tracks are due to alpha-particles occurring at random in time—that is, if the number occurring in a time $\delta T$ is proportional to $\delta T$—then from (2) the number of tracks with breadth between X and $X + dX$, is proportional to $XdX$, and so increases linearly with X. The observed distribution of the tracks in breadth shown in fig. 7 is consistent with this view, though there is a slight defect in the numbers between 1 and 2 mm. But this may well be due to chance. More than half of the tracks of less than 1 mm breadth are probably associated with the cosmic rays, the rest being of chance occurrence. The upper limit to the breadth of the tracks is merely that breadth to which

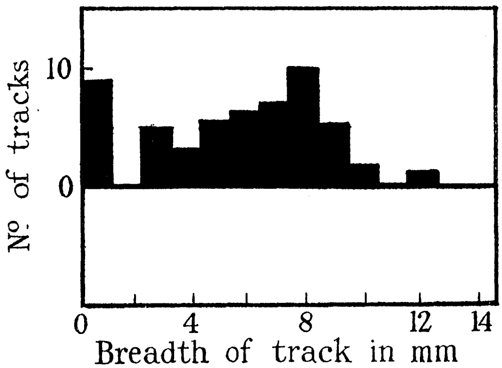



Fig. 7—Number of broad tracks.

they will grow in the time taken for the ions to cross the chamber under the electric field, and so is large when a weak electric field is used.

If the broad tracks are due to alpha rays, then their rate of occurrence in the chamber is about five per minute. This works out at about 70 per hour per 100 sq. cm area, which is of the order of the expected contamination.*

Sometimes quite short tracks are observed, very much shorter than any known alpha-rays, figs. 13, 14 and 15, Plate 2. Some of these may possibly be due to the recoil tracks produced when a neutron collides with a heavy nucleus. But there is often an alternative explanation. The ions move in air at 1·5 atmospheres under the field of about 2·5 volts per cm with a velocity of about 3 cm $\text{sec}^{-1}$. So in a time of $\frac{3}{4}$ second they have moved about 2·3 cm from where they were formed; that is, a distance of the order of half the height of the chamber.

* Beardon, 'Rev. Sci. Instr.,' vol. 4, p. 271 (1933).

Suppose an alpha particle happens to be emitted in the material of, say, the piston, so as just to emerge into the gas and produce a track of few millimetres long. Then all the ions of one sign will be drawn into the middle of the chamber and therefore photographed as a short nearly round blob.

So when a *single* small round blob is observed it is not possible always to conclude with certainty that it corresponds to a particle of short range. The occurrence of such short-range particles can only be considered certain when a double track showing both positive and negative ion groups is observed, or when the position in the chamber is such as to exclude the other explanation. It is interesting to compare the tracks in figs. 14, 15, which are probably due to parts of the track of a radio-active contamination alpha-particle, with fig. 13, which was photographed when using a neutron source, and is almost certainly a neutron recoil track.

Some photographs have recently been taken by Locher* with the same counter-controlled method, but with argon in the chamber and three instead of two counters. Locher reports several neutron recoil tracks apparently associated with cosmic ray showers and shows their close resemblance to the recoil tracks produced by a neutron source. It appears that some of the tracks observed by Locher are as broad as 1·5 cm. If the argument given here is valid, such very broad tracks were certainly not due to particles which were contemporary with the cosmic rays. They must, therefore, be attributed to random events, not related to the showers. Locher also observed thinner tracks which may have been contemporary with the cosmic rays.

That neutrons might be associated with the showers and yet occur half a second earlier must be considered as unlikely. It is equally unlikely that such broad tracks are due, not to the diffusion of ions from a line, but to some new form of spatially extended ionizing agent.

I wish to express my pleasure and gratitude derived from the collaboration during the last two years with my colleague G. P. S. Occhialini, who was closely associated with nearly all the work described in this paper.

The cost of the solenoid was met by a grant from the Government Grant Committee of the Royal Society.

I wish to express my appreciation of the interest taken by Lord Rutherford in this work and for the facilities which he has put at our disposal in the Cavendish Laboratory.

* *Loc. cit.*

I also wish to thank the staff of the Laboratory, in particular Messrs. Lincoln, Fuller, and Aves, for their assistance in constructing the apparatus.

## *Summary*

When Geiger counters are used to actuate a cloud chamber, the tracks formed will have a breadth which can be calculated by taking into account the diffusion of the ions, during the time $\tau$ from the instant of their formation to the instant of drop formation. The breadth of a track varies as $\tau^{\frac{1}{2}}$. It is found that when $\tau = 0{\cdot}01$ second, tracks can be obtained in air at $1{\cdot}5$ atmospheres, which are about $\frac{3}{4}$ mm broad. It is almost impossible to obtain tracks, at this pressure, very much finer than this owing to the very large forces required to produce the necessary acceleration of the piston. The breadth of the tracks, for a given delay $\tau$, should inversely be proportional to the pressure of the gas.

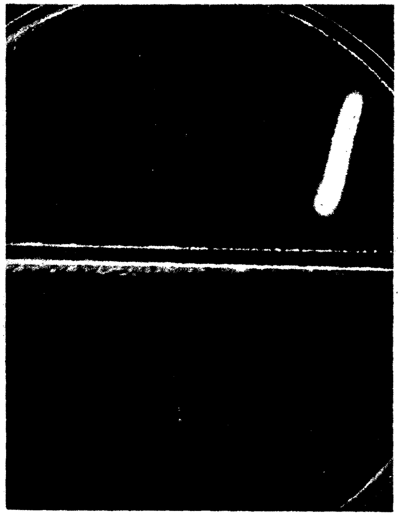
Special care is required in the design of the release mechanism, to reduce as far as possible the time taken to release the valve controlling the expansion. To obtain a quick release, the release magnet must be made quite small and of small inductance.

Since not more than 3000 gauss could be obtained with the water-cooled solenoid used in the first experiment, a new chamber has been made to fit between the pole pieces of a large electro-magnet, which could produce about 10,000 gauss.

The tracks are liable to various kinds of distortion, which may be of great importance as limiting the accuracy of measurement of the tracks.

Measurement of the track breadths in oxygen and hydrogen confirm the theoretical calculations based on the diffusion theory. When the tracks of heavily ionizing particles are considered, it is found that their apparent breadth is greater than that of electron tracks. Their *photographic breadth* depends on the intensity of the light and on the optical arrangement. Measurements confirm the theoretical variation of track breadth with time of formation.

The broad tracks often observed are interpreted, in the light of the discussion, as due mainly to alpha particles from radio-active materials in the walls of the chamber. The numbers observed of different breadths agree with this assumption. It is probable therefore that they have nothing to do with the cosmic radiation.



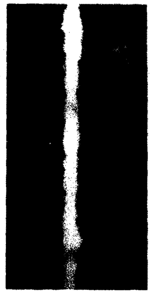
8

9

*0·01 second*

10a

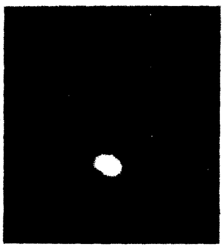
10b



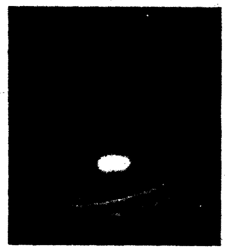
11

*0* *1 cm.*

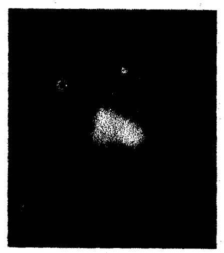
12



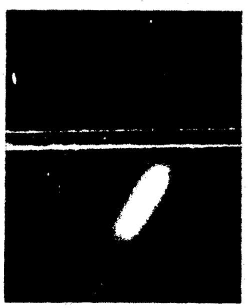
13



14



15



16

*0* *3 cm.*

17

*0* *1 cm.*

18

19

20

21

## DESCRIPTION OF PLATES

### Plate 2

Fig. 8—A single cosmic ray track (E $\sim 200 \times 10^6$ volts), and a broad track due probably to an early contamination alpha-particle.

Fig. 9—An oscillograph record of fall of piston.

Fig. 10—Enlarged photograph of electron track in oxygen. $X_1 = 0 \cdot 85$ mm.

Fig. 10a—Enlarged photograph of electron track in hydrogen, showing clearly the individual droplets. $X_1 = 1 \cdot 8$ mm.

Fig. 11—Enlarged photograph of proton track in oxygen. $X_p = 1 \cdot 3$ mm.

Fig. 12—Track of particle of energy 45 million volts, taken in a magnetic field of 10,000 gauss, with the chamber described in Section 8.

Fig. 13—A neutron recoil track using a source of Po + Be. (Chadwick, Blackett, and Occhialini, 'Proc. Roy. Soc.,' A, vol. 144, p. 235 (1934)).

Fig. 14—Photograph of short track found on photographs of cosmic rays. Although very like fig. 13, which latter is certainly due to a neutron recoil track, it is probable that 14 represents *part* of an early contamination alpha-particle track.

Fig. 15—A short broad track found on a cosmic ray photograph. The positive and negative ion groups are here both visible so that the time can be calculated $\tau = 0 \cdot 21$ second $X_p = 0 \cdot 65$ cm. The two tracks are separated by $1 \cdot 1$ cm and one appears shorter than the other because it has been displaced by the field nearly out of the illuminated part of the chamber.

Fig. 16—A typical broad track.

Fig. 17—The same enlarged so as to show the individual droplets. Fig. 4 shows the variation of observed drop direction with distance from the track centre.

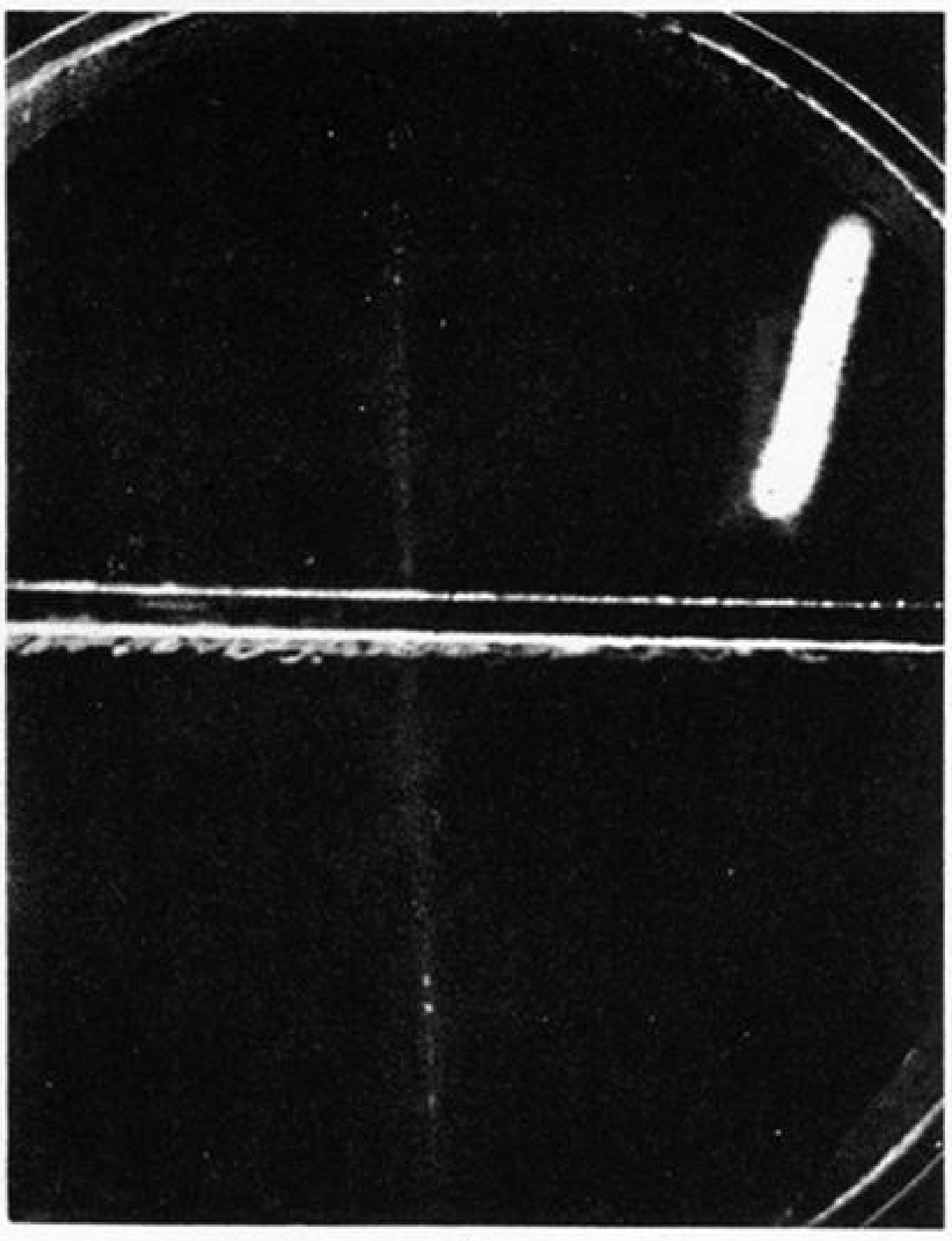
### Plate 3

Fig. 18—A complicated shower, showing about 16 tracks, some of high and some of low energy, in no very simple relation to each other (H = 2200 gauss).

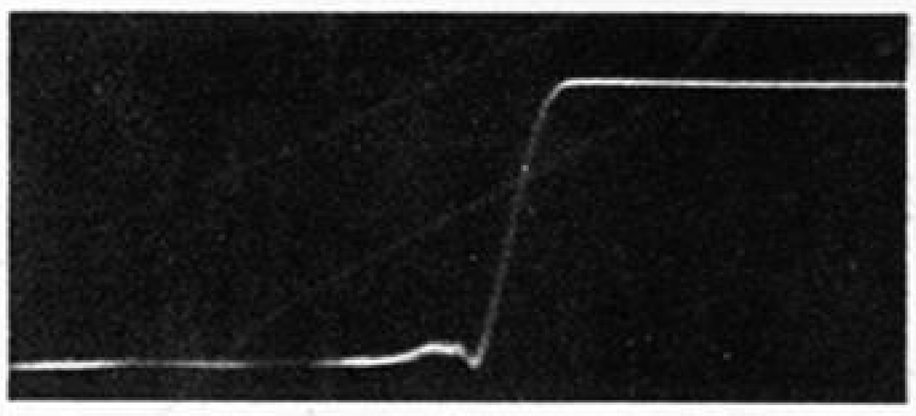
Fig. 19—A shower with four tracks of which two are positrons and two electrons. The energies are 230, 150, 55, and 20 million volts. The round blob probably represents *part* of an early contamination alpha particle (H = 3300).

Fig. 20—Another complicated shower of about 19 tracks, mostly of rather low energy about 6 million volts. It is almost impossible to find any simple chracteristics of this shower. It is therefore not possible to tell for certain the direction of the particles or therefore their charge. (H = 3300.)

Fig. 21—A single ray of energy greater than $2 \times 10^8$ volts going straight through the chamber. A circular track due to a particle of about 800,000 volts. A broad track probably due to a contamination alpha passing through the chamber about $\frac{1}{2}$ second before the expansion. (H = 2200.)

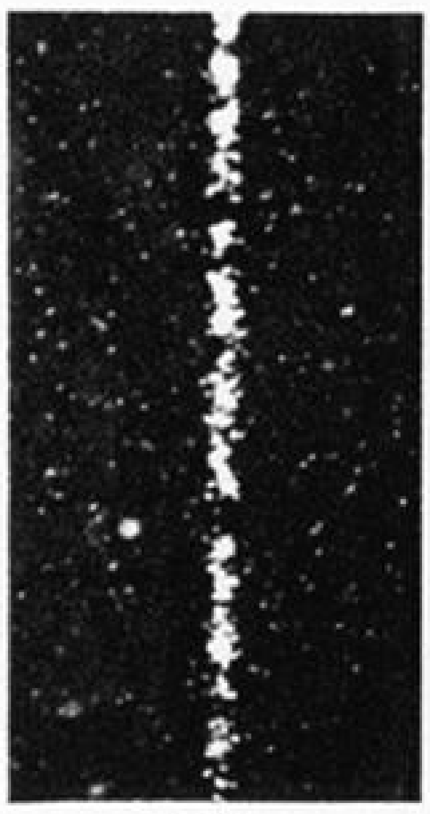


8



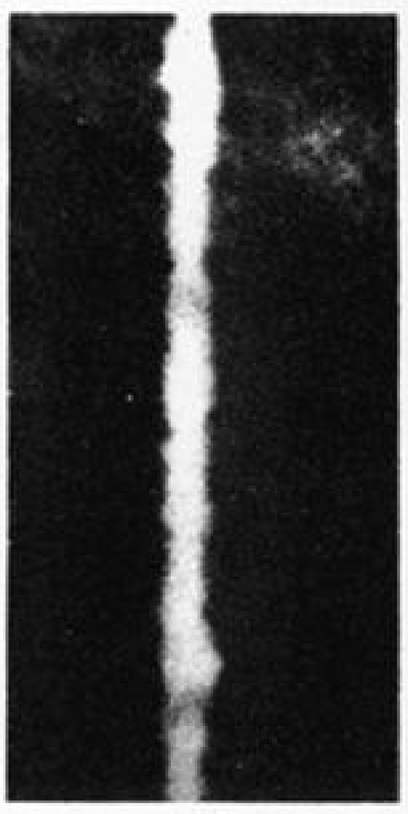
9

0·01 second



10a

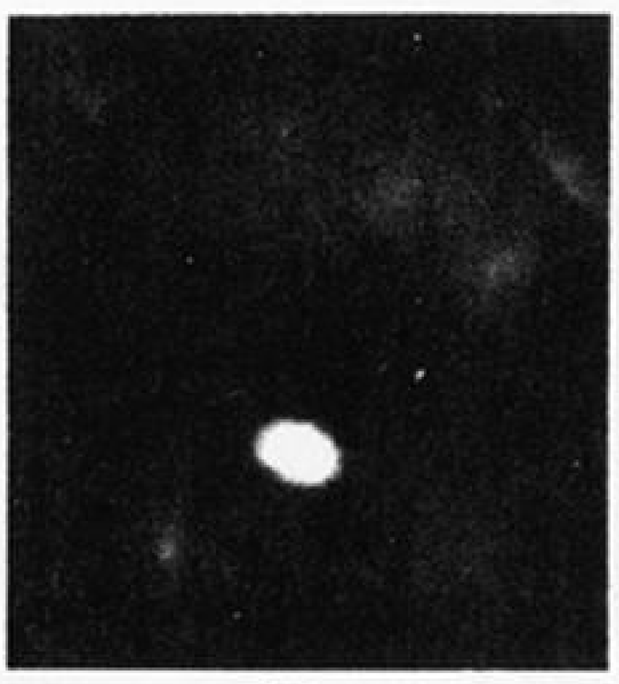
10b



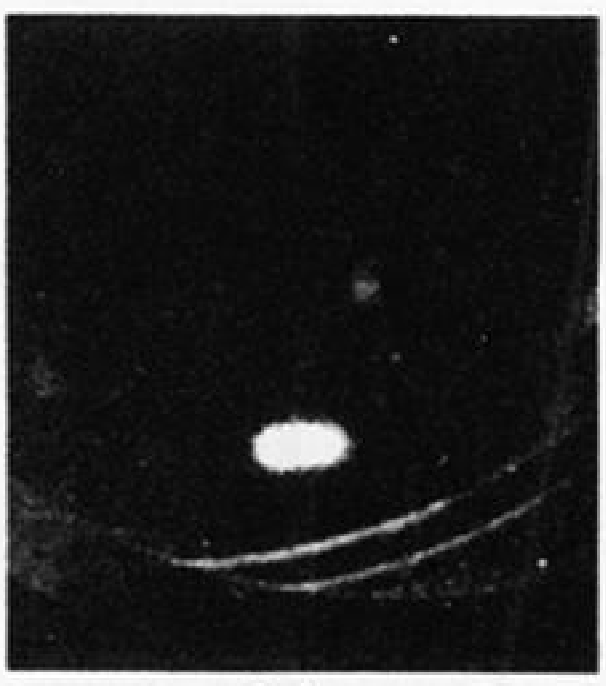
11

0 1 cm.

12

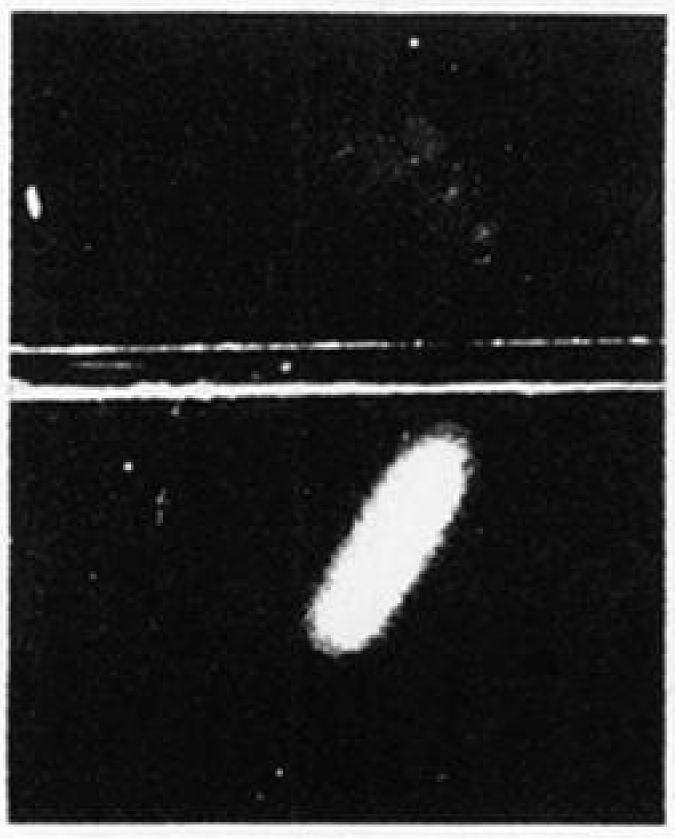


13



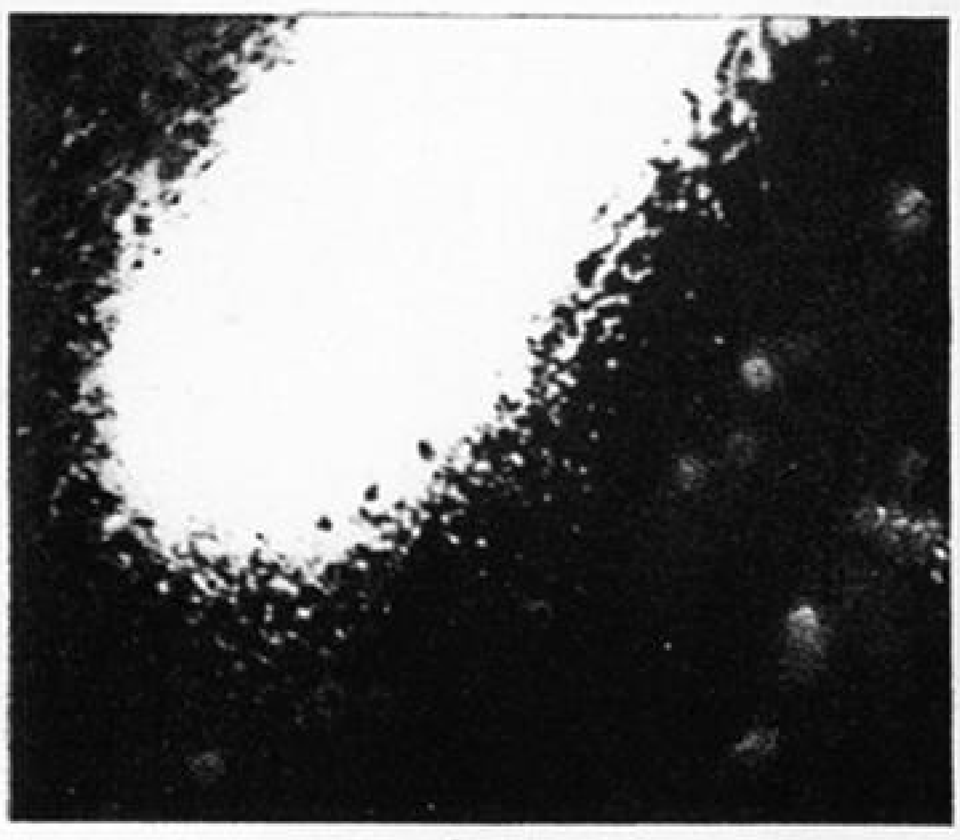
14

15



16

0 3 cm.



17

0 1 cm.

PLATE 2



FIG. 8—A single cosmic ray track (E $\sim 200 \times 10^6$ volts), and a broad track due probably to an early contamination alpha-particle.

FIG. 9—An oscillograph record of fall of piston.

FIG. 10—Enlarged photograph of electron track in oxygen. $X_1 = 0 \cdot 85$ mm.

FIG. 10A—Enlarged photograph of electron track in hydrogen, showing clearly the individual droplets. $X_1 = 1 \cdot 8$ mm.

FIG. 11—Enlarged photograph of proton track in oxygen. $X_p = 1 \cdot 3$ mm.

FIG. 12—Track of particle of energy 45 million volts, taken in a magnetic field of 10,000 gauss, with the chamber described in Section 8.

FIG. 13—A neutron recoil track using a source of Po + Be. (Chadwick, Blackett, and Occhialini, 'Proc. Roy. Soc.,' A, vol. 144, p. 235 (1934)).

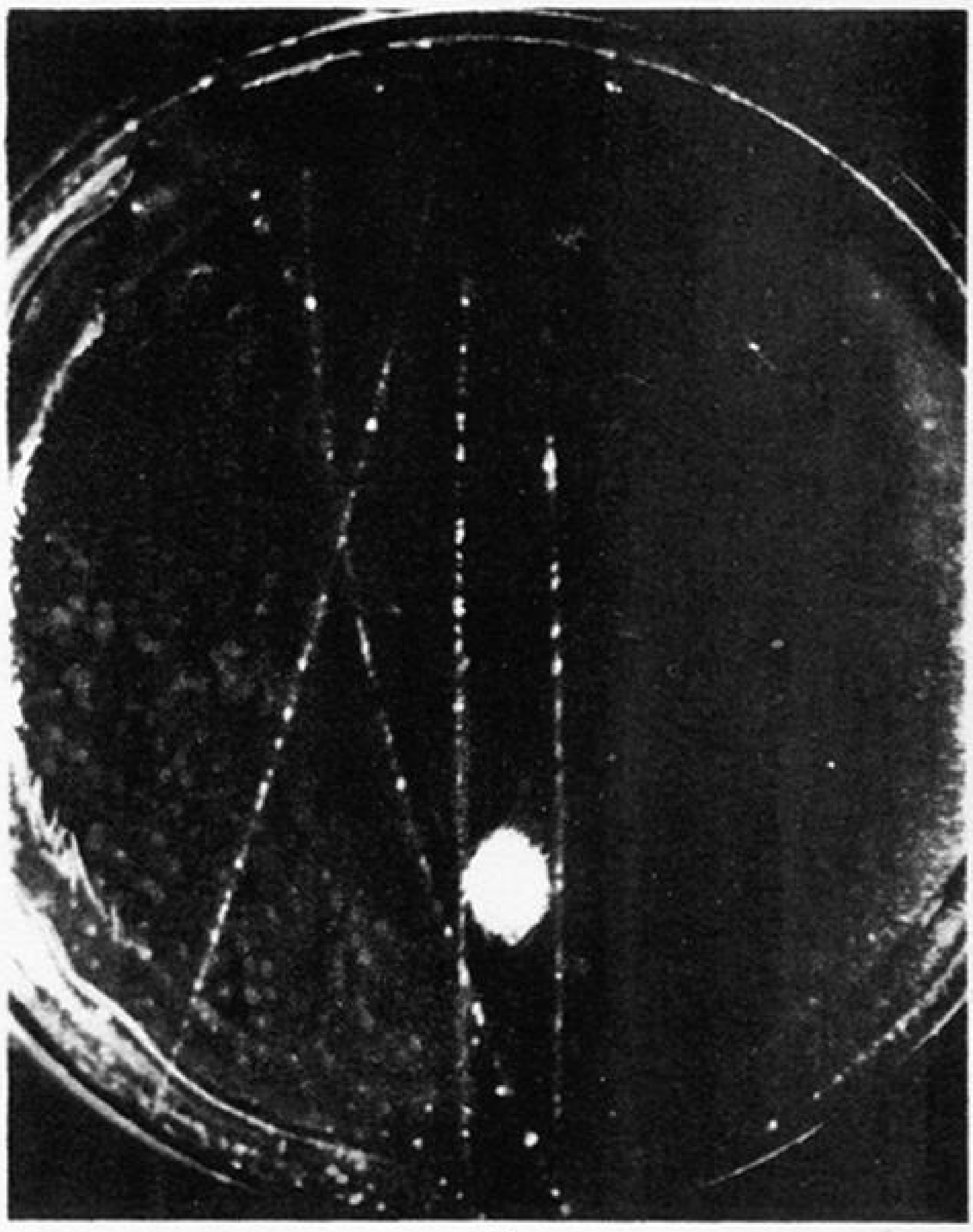
FIG. 14—Photograph of short track found on photographs of cosmic rays. Although very like fig. 13, which latter is certainly due to a neutron recoil track, it is probable that 14 represents *part* of an early contamination alpha-particle track.

FIG. 15—A short broad track found on a cosmic ray photograph. The positive and negative ion groups are here both visible so that the time can be calculated $\tau = 0 \cdot 21$ second $X_p = 0 \cdot 65$ cm. The two tracks are separated by $1 \cdot 1$ cm and one appears shorter than the other because it has been displaced by the field nearly out of the illuminated part of the chamber.

FIG. 16—A typical broad track.

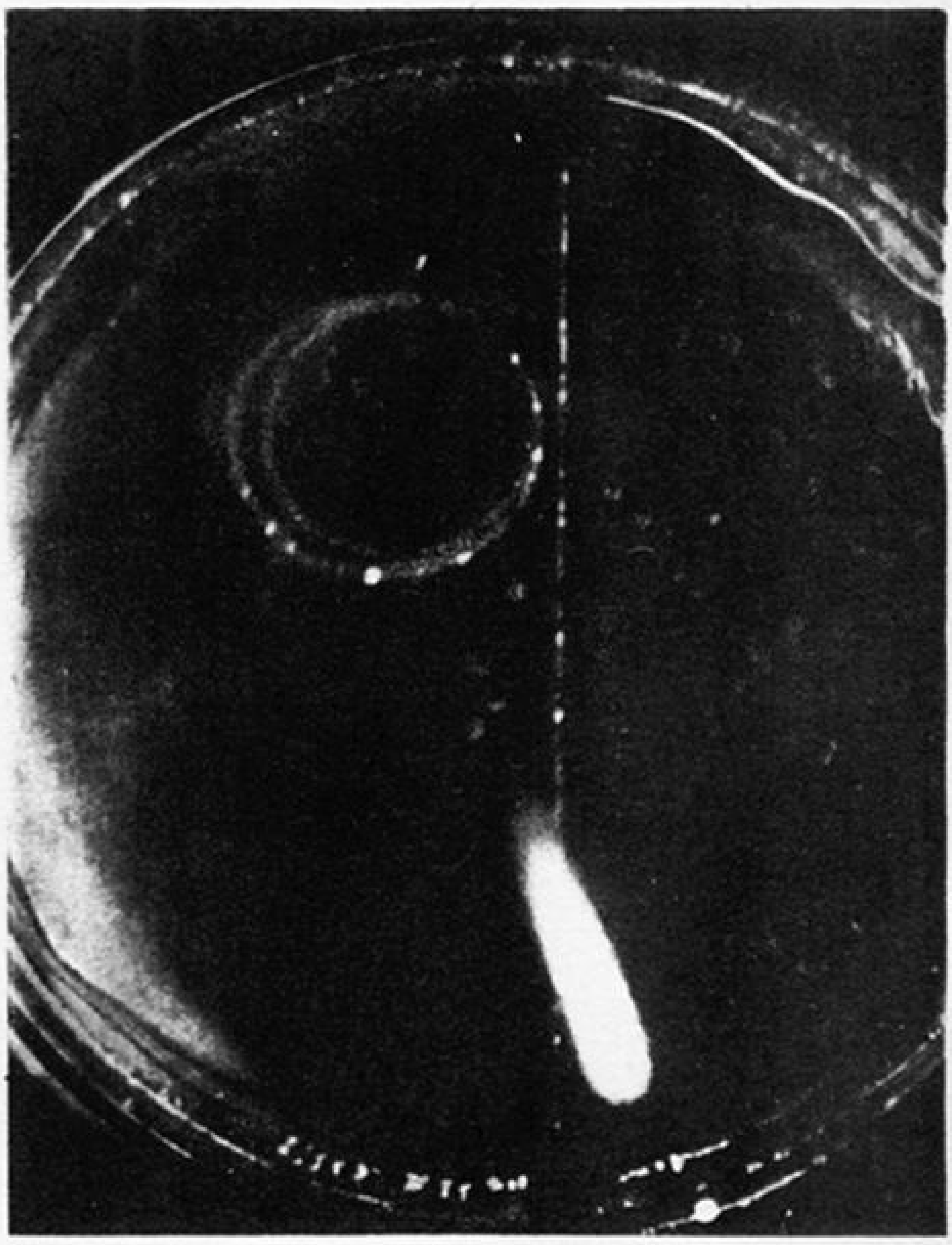
FIG. 17—The same enlarged so as to show the individual droplets. Fig. 4 shows the variation of observed drop direction with distance from the track centre.

18



19

20



21

PLATE 3

FIG. 18—A complicated shower, showing about 16 tracks, some of high and some of low energy, in no very simple relation to each other (H = 2200 gauss).

FIG. 19—A shower with four tracks of which two are positrons and two electrons. The energies are 230, 150, 55, and 20 million volts. The round blob probably represents *part* of an early contamination alpha particle (H = 3300).

FIG. 20—Another complicated shower of about 19 tracks, mostly of rather low energy about 6 million volts. It is almost impossible to find any simple chracteristics of this shower. It is therefore not possible to tell for certain the direction of the particles or therefore their charge. (H = 3300.)

FIG. 21—A single ray of energy greater than $2 \times 10^8$ volts going straight through the chamber. A circular track due to a particle of about 800,000 volts. A broad track probably due to a contamination alpha passing through the chamber about $\frac{1}{2}$ second before the expansion. (H = 2200.)