CLOUD CHAMBER PHOTOGRAPHS OF THE COSMIC RADIATION

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FOREWORD by
Professor P. M. S. BLACKETT, F. R. S.

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FOREWORD

by Professor P. M. S. BLACKETT, F.R.S.

Nobel Laureate

THE LAST TWO decades have seen an increasing use of two experimental methods, the cloud chamber and the photographic emulsion, by which the tracks of individual sub-atomic particles of high energy can be studied. Progress in the study of these particles would have been extremely slow were it not for these two methods, so contrasted in their technique but so similar in their results. All but one of the now known unstable elementary particles have been discovered by one or other of these techniques; the positive and negative μ-mesons and the various types of charged and uncharged V-particles by the cloud chamber; the positive and negative π-mesons and the $\varkappa$- and τ-mesons by the photographic emulsion. Only the π^0-meson was first discovered by other means, although a few months later it was also found in photographic emulsions.

Since both methods give us pictures of what single particles do—and what any particle does is much dependent on chance—the pictures obtained are all different in detail and often very complicated. An important step in any investigation using these methods is the interpretation of a photograph, often of a complex photograph, and this involves the ability to recognise quickly many different types of sub-atomic events. To acquire skill in interpretation, a preliminary study must be made of many examples of photographs of the different kinds of known events. Only when all known types of event can be recognised will the hitherto unknown be detected. Such new events may be extremely rare, and it is important that, when found, the chamber record should prove to be technically suitable for accurate measurement. Thus an essential, and by no means always an easy, task which faces the user of the cloud chamber method, is to maintain a high standard of technique over long periods of time. If once the level drops too far, reliable interpretation and accurate measurement become impossible.

I think the guiding object in this compilation by Drs. WILSON and ROCHESTER of a volume of carefully selected cloud chamber photographs, is to facilitate the acquiring of these two essential skills, that of interpretation and that of recognition and attainment of high technical quality. I believe that the two authors have succeeded brilliantly in their task, and that the book will prove a quite indispensable aid to all those research workers who are investigating sub-atomic events by the cloud chamber method. Moreover to all students of the physics of elementary particles, even if they are not themselves engaged in original investigation, the book should prove an invaluable means of acquiring a clear picture of the various sub-atomic processes, and so should prove a great aid to physical understanding. To many non-physicists too I think the book should make a definite appeal, if only by the visual beauty of the patterns of the tracks woven by these energetic elementary particles. It should do more than this, however, for it must surely help us to make clear that this world of sub-atomic events is one which can be easily visualised and understood without the aid of complicated mathematics or the mastery of deep theories. If one asks why some of these complicated events happen, one may be led into the subtle intricacies and uncertainties of modern fundamental theoretical physics, but if the experimenter contents himself with asking how they happen, then these pictures, and the attached commentaries, are an ideal guide to the world of energetic elementary particles.

Manchester, Dec. 1951.

PREFACE

It is now rather more than ten years since the "Atlas typischer Nebelkammerbilder" of Gentner, Maier-Leibnitz and Bothe was published. This volume covered the whole field of application of the cloud chamber, and illustrated in a striking way the varied contributions made by cloud chamber investigations in many branches of the physics of the atomic nucleus and of cosmic rays.

When, some two years ago, the possibility of a revised edition of the "Atlas" was under consideration, it became clear that the advances of the last ten years were so extensive that representative photographs covering all applications of cloud chambers could no longer be appropriately brought into a single volume. It was decided to publish two volumes, and we were invited to prepare one of these, which would cover the application of the cloud chamber method to problems of cosmic ray physics.

In this volume it has been our aim to include both particular photographs of historic importance and typical examples of the principle phenomena of the subject, weighting our selection towards topics in which the cloud chamber method is at present making, and may be expected to continue to make, important contributions. We accordingly give relatively few examples of pure electron-photon cascade phenomena, and of the characteristic behaviour of the abundant μ-meson, and by contrast, many of high energy nuclear interactions, and in particular of the recently discovered V-particles. The cloud chamber is an instrument of considerable versatility, and in the legends attached to the photographs it has seemed useful to add brief descriptions of construction, control, operating conditions and performance, which will give some indication of the wide variations of design which have proved of value under different conditions. In addition, although technical features of operation do not in general lend themselves to illustration in single photographs, we include a section on problems of selection and of technical quality as they are related to interpretation.

Any record of cloud chamber application would be misleading which did not adequately stress the element of critical interpretation which is necessary if photographs are to yield the full information contained in them. With this in view, we have tried to make the legends to photographs illustrate the process of interpretation as well as the accepted description of the central phenomenon. The legends are therefore long, and in many cases discursive, and occasionally offer alternative interpretations which are not resolved in the photographs or in the additional data available. We hope, however, that they will, for readers who are interested, provide a useful series of exercises in problems of interpretation which are fairly typical of those encountered in cosmic ray applications.

We offer this volume as a tribute to Professor P. M. S. Blackett, F.R.S., Director of the Physical Laboratories in the University of Manchester, an outstanding pioneer in the application of the cloud chamber as a tool of precision to cosmic ray investigation and to whom we owe, as pupils of many years standing, an exhaustive training in the art of cloud chamber operation and in the discipline of interpretation of cloud chamber photographs.

Dec. 1st. 1951.

G.D.R.
J.G.W.

CONTENTS

Section I: Technical Features of Operation

Section II: Electrons and Cascade showers

Section III: Slow μ-mesons and their decay

Section IV: Nuclear disintegrations and interaction of secondary particles

Section V: V-particles

Section VI

ACKNOWLEDGMENTS

A truly representative collection of photographs would not have been possible without the active cooperation of workers in all parts of the world, and we are very greatly indebted to all those from whom we requested photographs, and who without exception gave us every assistance. Our particular thanks are due to Dr. G. R. Evans, of Aberystwyth, through whom we were able to obtain photographs taken by the late Professor E. J. Williams, and to the Director of the Science Museum, South Kensington, who supplied prints of early photographs by Professor D. Skobeltzyn, of which the original negatives no longer exist.

We are most grateful to Professors Anderson, Blackett, Brode, Cocconi, Fretter, Gregory, Hazen, Johnson, Kunze, Leprince-Ringuet, Ney, Nishina, W. M. Powell, Rossi, Salvini, Street and Thompson, and Drs. Butler, Cohen, Daudin, Evans, Hayward, Hodson, Jopson and Rosser, all of whom supplied photographs. We are also indebted to the editors and publishers of the following publications, for permission to reproduce photographs first published in their pages: the American Journal of Physics, Annales de Physique, Comptes Rendus de l'Académie des Sciences, the Journal of the Franklin Institute, Nature, the North-Holland Publishing Co., il Nuovo Cimento, the Philosophical Magazine, the Physical Review, the Princeton University Press, the Proceedings of the Physical Society of London, the Proceedings of the Royal Society, Reviews of Modern Physics, Sigma Books Ltd., and the Zeitschrift für Physik.

Finally we wish to record our thanks to our colleagues at Manchester for their interest and advice throughout the preparation of the book, and in particular to Dr. C. C. Butler and Mr. K. H. Barker, with whom we have had invaluable discussions on the interpretation and presentation of the photographs. Many of the photographs used were prepared by Mr. Hugh Martin, and we are most grateful to him for his careful and patient work.

G.D.R.
J.G.W.

SECTION I

TECHNICAL FEATURES OF OPERATION

Diffused cloud-chamber tracks

Plates 1, 2, 3 and 4. Photographs of tracks of cosmic-ray particles in which the ions have been allowed to diffuse before condensation has taken place, illustrating the formation of drops, the distribution of ions in the track, and the efficiency of condensation.

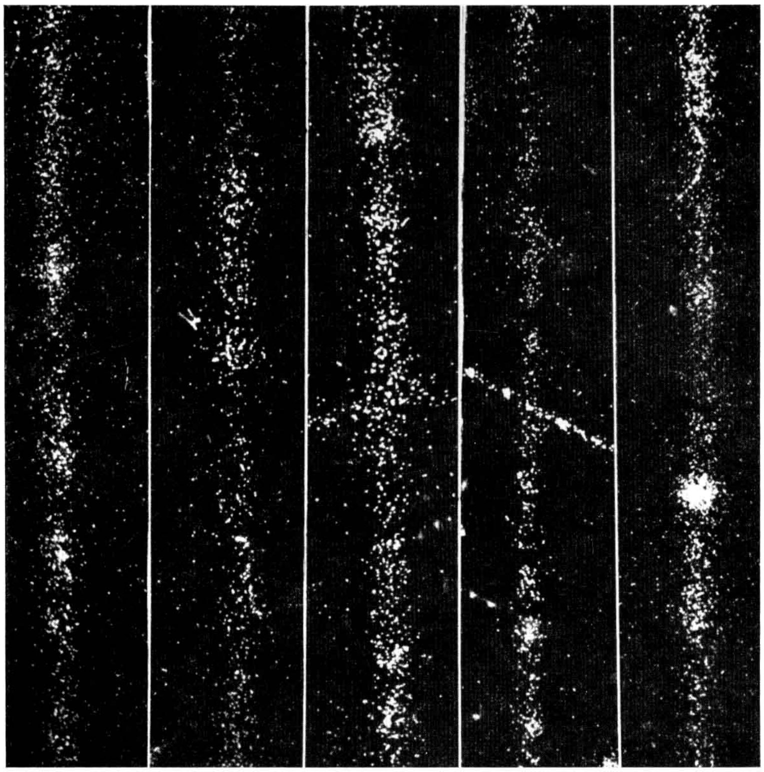

Plate 1. R. B. Brode, Berkeley, Rev. Mod. Phys. **11**, 222 (1939). [See also D. R. Corson and R. B. Brode, Phys. Rev. **53**, 773 (1938).]

The chamber was 30 cm. in diameter and 6 cm. in depth, illuminated from the side, the illuminated region being 2 cm. deep. The gas filling was mainly nitrogen, at a pressure of approximately one atmosphere, with ethyl alcohol-water mixture as condensant. The chamber was counter-controlled and was operated in a magnetic field of 2300 gauss. The tracks were photographed with a single Elmar lens of focal length 5·0 cm., with an image reduced in the ratio 1:7·5, the apparent diameter of the drops in the chamber being 0·2–0·4 mm. The calculated diameter of the drops from observations of the rate of fall in the chamber was 0·04 mm.

The tracks were about 5 mm. broad in the chamber, and the time intervals used in photographing them were as follows:

Arrival of particle	$t = 0{\cdot}00$ sec.
Clearing field removed	$t = 0{\cdot}010$ sec.
Expansion completed	$t = 0{\cdot}200$ sec.
Lights on	$t = 0{\cdot}245$ sec.
Lights off	$t = 0{\cdot}250$ sec.

It will be noted that the main delay which allowed diffusion of the ions was 0·2 sec. The drops were allowed to grow for 0·045 sec. before being photographed. The duration of the light flash was kept small, i.e. 0·005 sec., in order that the free fall of the drops, in this time interval, should be only a small fraction of the apparant diameter of the drops. The delay of 0·2 sec. was sufficient to allow clusters up to about 250 drops in size to be counted.

The general features of the distribution of ions in a track are well shown in these photographs. The wide fluctuation in the density of ions along the track may be noted. Clusters such as the large one on the track at the extreme right-hand side are caused by secondary electrons with energies of several kilovolts. A non-contemporary track can be seen crossing one of the diffused tracks.

These tracks are reproduced 1·2 times their size in the chamber.

Preferential sign condensation

Plate 2

Plate 2. W. E. Hazen, Berkeley. Photograph published in "Cosmic Ray Physics" by D. J. X. Montgomery. Princeton University Press (1949) Plate VI.

The photograph shows a small electron shower of diffused tracks in which the positive ion columns have been separated from the negative ion columns by leaving the electrostatic clearing field on during the period between the passage of the shower and expansion. The positive ion columns are the left-hand members of the pairs of tracks. The chamber was counter-controlled and contained air at a pressure of 90 cm. Hg. with an alcohol-water mixture as condensant.

A vertical temperature gradient of about 0·5° C. per 30 cm. in the chamber resulted in an increase of supersaturation from top to bottom, and the effect was a gradual increase in the number of negative ions upon which condensation took place with the change in the supersaturation. Practically complete condensation has occurred on the positive ions at even the lowest value of supersaturation. (Note that if the condensant had been water alone, complete condensation would have occurred first on the negative ions.) The gross distortion of the tracks is a consequence of their age.

Preferential sign condensation is an important feature of cloud chamber work, particularly when the ionization produced by a particle is determined from drop counts. It is necessary that complete condensation shall have taken place on the ions to be counted. When ions of either sign are unseparated (as in Plate 1) there is no direct method of establishing that complete condensation has indeed taken place. If, however, the ions are separated, as in the present example, into columns of positive and negative ions, it is possible to establish criteria by which conditions in which complete condensation has taken place in the more heavily condensed column may be recognised.

This photograph is reproduced at its correct size in the chamber.

Ionization in hydrogen

Plates 3 and 4. W. E. Hazen, Berkeley. (Unpublished.)

The photographs show the diffused and sign-separated tracks of an electron and of a slow, singly-charged, heavy particle in hydrogen at a pressure of 90 cm. Hg. Each photograph is approximately natural size. The excellence of the chamber conditions is shown by the fact that the columns of negative ions (the left-hand members of the pairs) are almost as dense as the positive columns, while the density of background drops is small. The quality of the drop images, which is very high at the centre of each picture, falls off somewhat at the edges. The lines across the photographs are clearing-field wires.

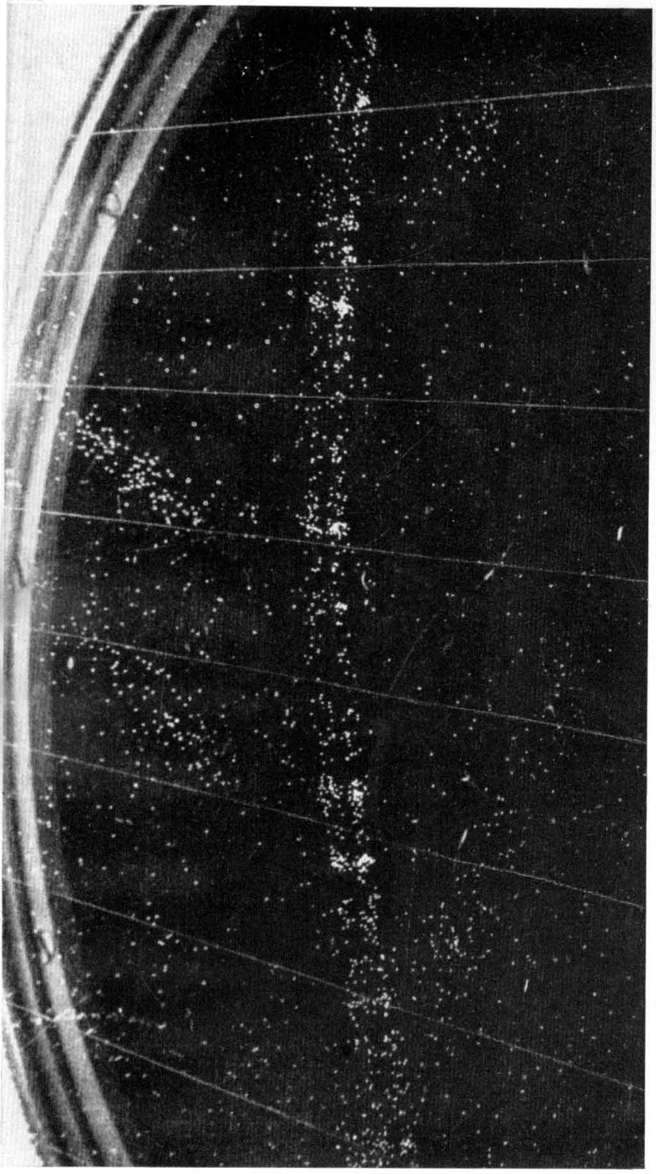

Plate 3

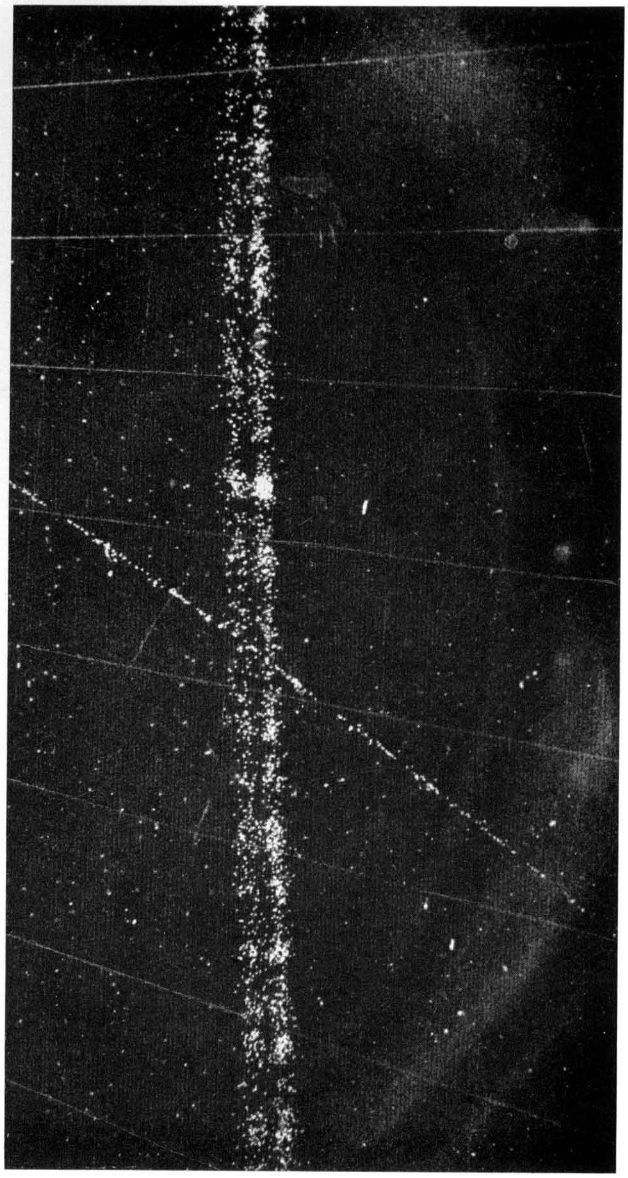

Plate 4

Plate 3. The track of an electron of energy 10 MeV. The electrostatic field was perpendicular to the magnetic field, and the axis of the camera made an angle of about 40° with the direction of this field.

The ionization produced by this electron was near the minimum ionization for a fast charged particle in hydrogen. The electrons shown in Plate 2 also ionize near their minimum value, but it will be seen that the density of ionization along comparable tracks is much greater in nitrogen than in hydrogen. The theoretical ratio of the primary ionizations in nitrogen and hydrogen at N.T.P. is about 5:1, and the ratio of the drop densities on the two photographs is very roughly of the expected order of magnitude.

Plate 4. This photograph shows the track left by a slow, massive, cosmic-ray particle of charge e. The ionization is about 2·5 times minimum, indicating a velocity of about 0·6 c. A non-contemporary track crosses the diffused track: it is near minimum ionization and shows no separation in the electrostatic clearing field, and has been produced by a particle traversing the chamber after supersaturation has been established.

Relationship in time and space of counter-controlled tracks

Plates 5, 6, 7 and 8. G. D. Rochester and C. C. Butler, Manchester. (Unpublished.)

These photographs were taken in a chamber 30 cm. in diameter, 9 cm. deep, and filled to a pressure of 1·5 atmospheres with 80% argon and 20% oxygen. The condensant was a 3:1 alcohol-water mixture. Across the chamber was a lead plate 3 cm. in thickness, faced above and below with 1·8 mm. chromium-plated brass sheets. Photographs 5, 6 and 7 were taken without magnetic field; photograph 8 was taken in a field of 7100 gauss. The electrostatic clearing field was removed before expansion.

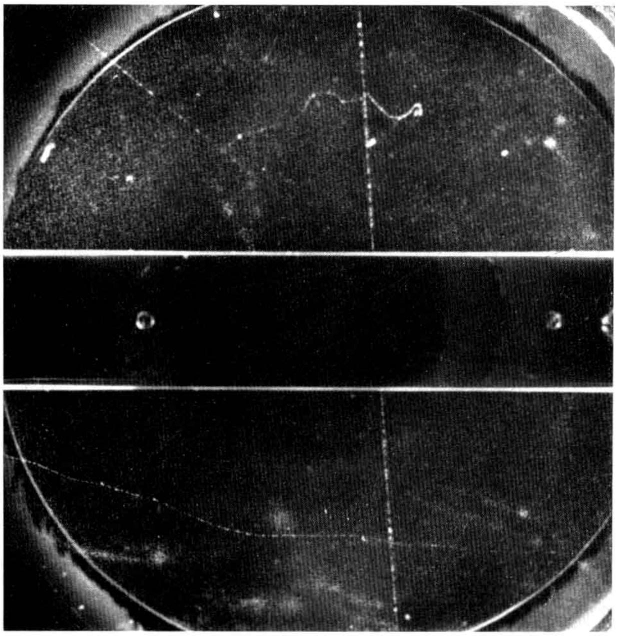

Plate 5

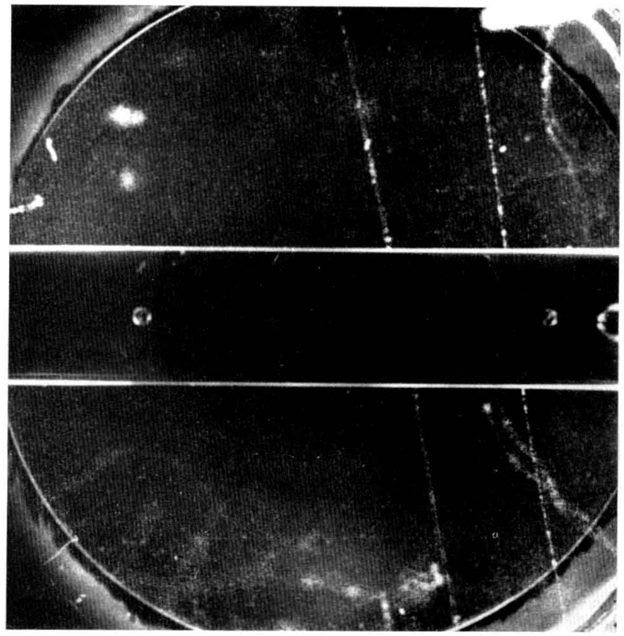

Plate 6

Plates 5 and 6. These photographs, taken under good conditions of condensation and illumination, show tracks of different age. In each case the particle which actuated the expansion is probably a meson. The particle which triggers the chamber produces a track which, for a particular chamber, operated under definite expansion conditions, has a well-defined width. In the present chamber the width of such tracks was about 0·7 mm., corresponding to a delay between the arrival of the particle and the onset of condensation of about 0·01 sec. If this type of track is called the controlled track, tracks of different age may be termed pre- or post-control, according to whether they have arrived before or after the controlled track. Plate 5 shows four tracks. The meson which triggered the chamber is the vertical track: the other three tracks are all post-control since they are narrower than the controlled track. Of these, one is a fast cosmic-ray particle and two are electrons. The electrons have an appearance typical of their energy; the electron in the upper part of the chamber is of a few kilovolts and the one in the lower part, a few MeV. The increase in ionization and scattering along the track of the slower electron as it comes to rest in the gas of the chamber is well shown.

In Plate 6 the control track is to the right-hand side of the chamber. The other particle which has formed a more diffuse track is also a meson. The width of this track is about twice the width of the control track and hence it must be pre-control of about four times the age. Both tracks show appreciable distortion within 1 or 2 cm. of the lead plate. The distortion probably arises from gas motion present in the chamber before expansion, and is, as would be expected, more pronounced on the older track. Old tracks from slow electrons may also be seen to the right-hand side of the chamber; these have clearly been formed long before the passage of the control track.

Plates 7 and 8. G. D. Rochester and C. C. Butler, Manchester. (Unpublished.)

These photographs illustrate some features of the application of stereoscopic photography in the analysis of cosmic-ray phenomena, the position and separation of the lenses being such that a pair of images 4 cm. apart is formed on 35 mm. film. This separation of images, about 25 mm. in diameter, is suitable for direct viewing with a stereoscope.

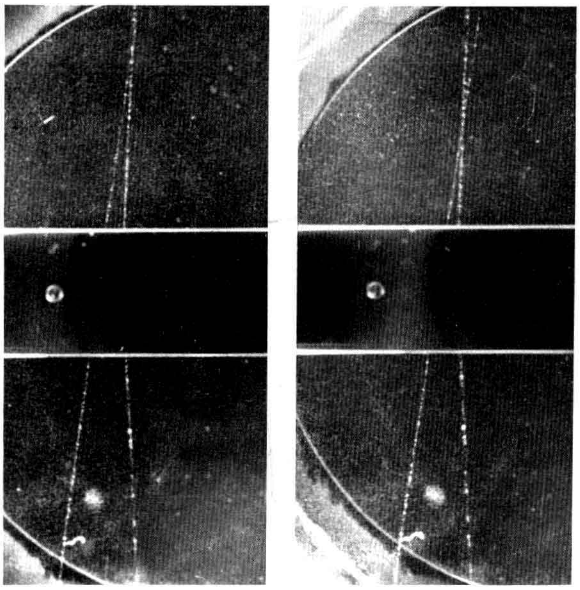

Plate 7

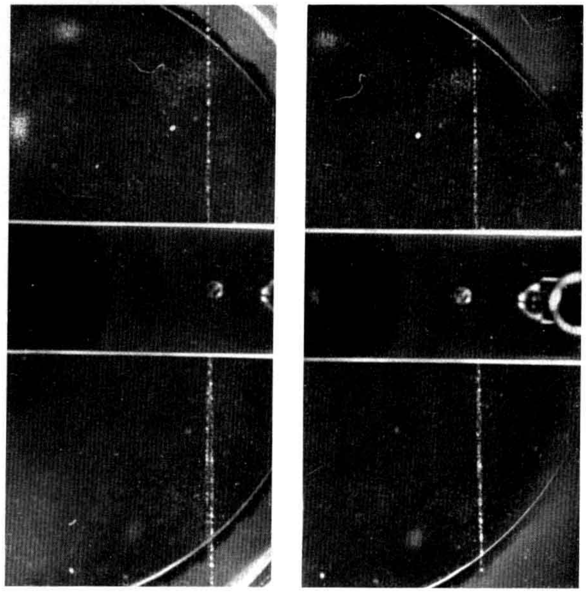

Plate 8

Plate 7 shows two charged particles which penetrated the lead plate, and had only the left-hand side picture been available it might have been erroneously interpreted as an associated pair of penetrating particles. Actually, however, a careful examination even of the left-hand picture alone shows that the tracks cross near to the top of the chamber and are not contemporary, the track to the left of the pair having traversed the chamber slightly later than the right-hand member.

Plate 8 shows a positive meson (momentum about 1 BeV/c.) which produced a negative knock-on electron (momentum about 100 MeV/c.) in the plate. The tracks below the plate are clearly separated in the left-hand photograph but are almost fused into one track in the right-hand photograph. The presence of overlapping tracks in the right-hand photograph may also be inferred from the difference in the density of ionization above and below the plate. Overlapping tracks from unresolved electron pairs with ionization densities approximately twice minimum have been noted in electron-photon showers. [See E. Hayward, Phys. Rev. **72**, 937 (1947).]

This photograph also shows considerable track distortion near the upper surface of the lead plate. There is no comparable distortion below the plate, and it may be concluded that the temperature conditions are such that the gas in the lower half, but not in the upper half, of the chamber is stabilized.

Technical features of track formation near metal plates

Plates 9 and 10. Manchester. (Unpublished.)

These photographs illustrate the effect of chamber contamination and of distortions near to a metal plate; both were taken with the same apparatus, the plate being 1 cm. lead.

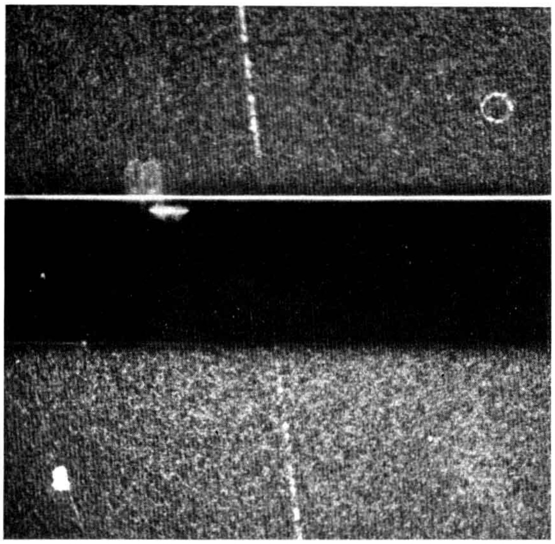

Plate 9

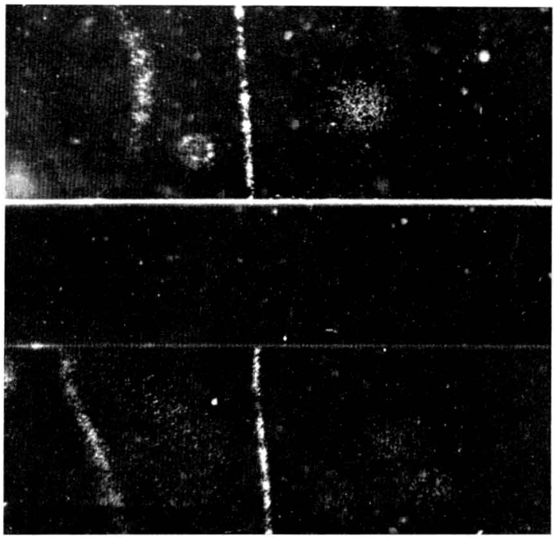

Plate 10

The first photograph (Plate 9) was taken with the chamber in poor condition, background condensation being developed at an unsatisfactorily low supersaturation. In order to obtain usable track images, it was necessary to operate with considerable background: thus in the main bulk of the chamber the expansion ratio was adjusted to the lowest possible value which would give adequate condensation on the ions of the track which traverses the plate. Close to the plate the supersaturation never quite reached the value obtained far from the chamber walls, on account of conduction of heat from the plate into the gas during the finite time of expansion. Accordingly, there was a layer of gas close to the plate in which condensation conditions were less favourable than those elsewhere. Background condensation is extremely sensitive to the supersaturation reached, and this layer is therefore marked by a reduction of background condensation. Since the supersaturation was adjusted to a value barely sufficient for track condensation in the main volume (in order to keep background condensation to a minimum), condensation on ions, and so on the track photographed, also failed at as much as 2 or 3 mm. from the surface of the plate. Plate 10 is typical, in contrast, of the chamber in good condition, a supersaturation well above the ion limit having been used without more than very slight background condensation. In this photograph also supersaturation near to the plate would be less than that in the main bulk of gas, but there was sufficient margin available for adequate condensation on ions to continue to within a small fraction of a millimetre of the plate surface.

Plate 10 also illustrates track distortions in the neighbourhood of the plate, of the kind which are considered to occur because of temperature differences between the plate and the chamber walls. In this example, the effect of these differences was apparently to stabilize the gas in the top half of the chamber and it is therefore likely that the plate was cool compared with the chamber walls. The distortion under the plate is easily recognised for 2 or 3 mm. from the plate, but if the photograph is viewed along the track, near grazing incidence, and this strongly distorted region ignored, it will be observed that the two halves of the track, above and below the plate, do not appear to meet in the plate. Thus, the distorted region extended far from the plate, and directional and curvature measurements on the whole track are suspect. Gross distortion near to a metal plate, as illustrated here, must as a rule be taken as an indication of distortion throughout the section of chamber concerned which will severely limit the precision of measurement.

Chamber contamination by liquid spray

Plate 11. J. C. STREET. (Unpublished.)

The lowest compartment of the chamber shows the images in intermittant illumination (mercury arc on 60 cycle A.C.), of numerous spray droplets thrown from the free liquid at the bottom of the chamber by mechanical vibration. A spray of this kind leads to a high concentration of background nuclei.

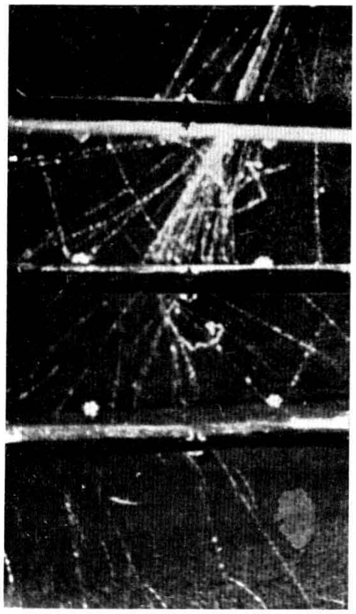

Plate 11

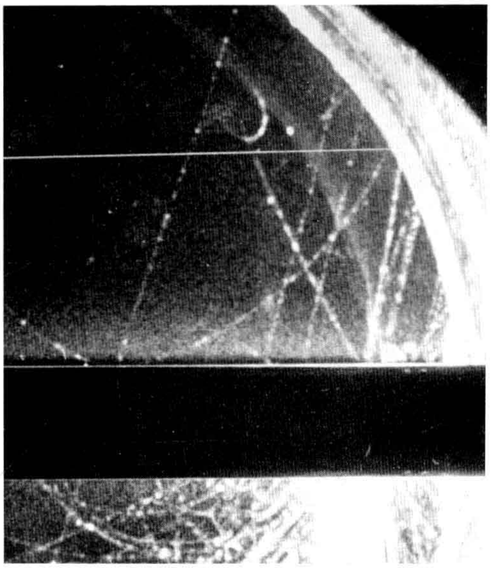

Plate 12

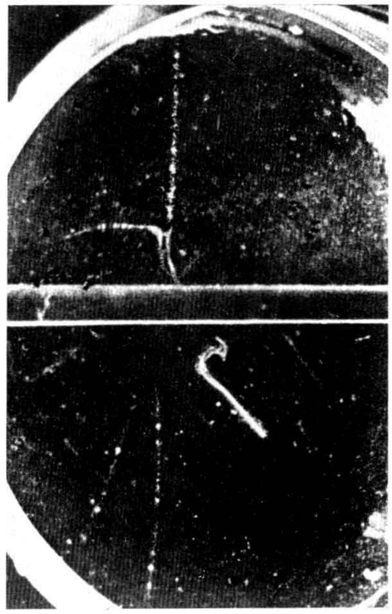

Plate 13

Distortion at edge of piston

Plate 12. R. ARMENTEROS, K. H. BARKER, C. C. BUTLER and A. CACHON, Manchester. (Unpublished.)

The photograph was taken with the chamber described under Plate 5, in which the piston is not, as is often the case, screened from the used section of the chamber by a velvet-covered gauze. The advantage of the present arrangement lies in the freedom from uncertain distortions arising from variations of porosity of the velvet, and also in speed of operation. The distortion illustrated here, which leads to a characteristic kink in the track, takes place particularly for tracks towards the back of the chamber, where they pass from in front of the rigid piston to the region in front of the supporting rubber annulus. This type of distortion is clearly connected with the complex motion of the rubber annulus at expansion.

(The distortion is most easily seen by sighting along the tracks.)

Turbulent distortion

Plate 13. P. M. S. BLACKETT and G. P. S. OCCHIALINI, Cambridge, Proc. Roy. Soc. A. **139**, 699 (1933).

The chamber, 13 cm. in diameter by 3 cm. deep, was controlled by counters above and below the chamber, and was filled with oxygen and water vapour at about 1·7 atmospheres. It contained a 6 mm. copper plate.

The photograph shows an event in which two electrons, of momentum about 12 MeV/c., and a heavy particle leave the lower surface of the plate. The striking feature of the picture is the violent and turbulent gas disturbance, certainly below, and probably also above, the plate. This disturbance was not a reproducible feature of operation, and it was suggested by BLACKETT (Proc. Roy. Soc. A. **146**, 289) that it may be due to an electric wind produced by the frictional electrification of hairs, or of the rubber diaphragm under rapid changes of tension. The former possibility is clearly the more appropriate to this picture.

Techniques of internal control of the cloud chamber

Plates 14–24. This series illustrates methods by which some part or all of the controlling counter or ion chamber system may be located within the cloud chamber, allowing the nature of the triggering particles to be identified.

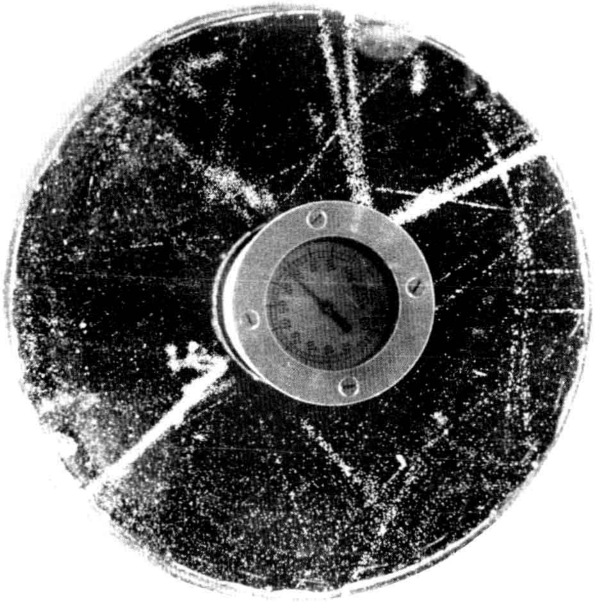

Plate 14. A disintegration in the wall of the ion chamber leading to four tracks, three heavily ionizing, one lightly ionizing.

Plate 15. An electron shower, originating in a 2·5 cm. lead plate placed immediately over the cloud chamber.

Plates 14 and 15.
H. S. Bridge, W. E. Hazen, B. Rossi and R. W. Williams, Cambridge, Mass. Phys. Rev. **74**, 1083 (1948).

The cloud chamber is controlled by an internal fast ion chamber, the work being carried out in order to gain a more precise understanding of the nature of the cosmic-ray phenomena responsible for "bursts" in ion chambers.

The ion chamber was 7·5 cm. in diameter with effective wire length 18 cm., wall of 1/32″ brass and filled to a pressure of 5 atmospheres of argon. It was mounted in a deep cloud chamber, about 30 cm. in diameter by 40 cm. deep, at the back of which an off-centre port was used to connect the cloud chamber to a separate expansion vessel. The connections of the ion chamber were taken out at the centre of the back of the cloud chamber. Oblique lighting scattered through about 45° was used. The photographs were taken at 3,050 m. or 4,300 m. altitude, in hydrogen at 80 cm. pressure. The combination of a rather slow chamber with hydrogen leads to very diffuse tracks.

Plates 16 and 17. M. J. Cohen, Princeton, N.J., Proc. Echo Lake Symposium, p 53 (1949).

The photographs were taken in a combined fast ion chamber and cloud chamber, operating with argon and alcohol vapour at a pressure of 115 cm. Hg. (expansion ratio 1·14 at 20° C.).

The two plates spanning the chamber are of aluminium, $17{\cdot}5 \times 10{\cdot}2 \times 0{\cdot}125$ cm.^{3}, and these, the perforated chamber back, the conducting surface of the front window and the entire housing of the chamber are earthed. The three signal plates are of copper $17{\cdot}1 \times 7{\cdot}6 \times 0{\cdot}033$ cm.^{3} (central) and $8{\cdot}4 \times 7{\cdot}6 \times 0{\cdot}033$ cm.^{3} (outer).

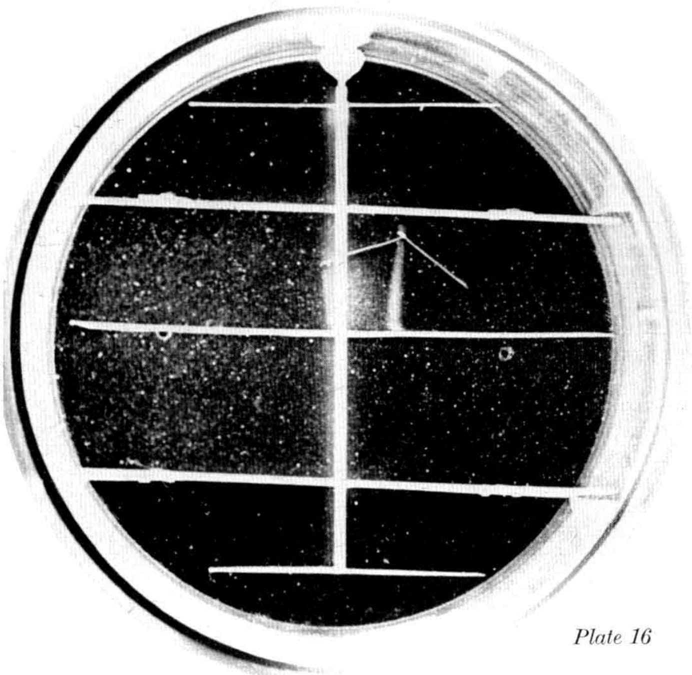

Plate 16

Plate 16. Three tracks are produced in the gas of the chamber, there being no indication of an ionizing primary. These are probably two protons, of energies 1·3 and 1·7 MeV. and a recoil nucleus.

Plate 17: A cascade shower crosses the chamber from back to front, downwards from the left. About 10 MeV. is dissipated by the shower in the chamber.

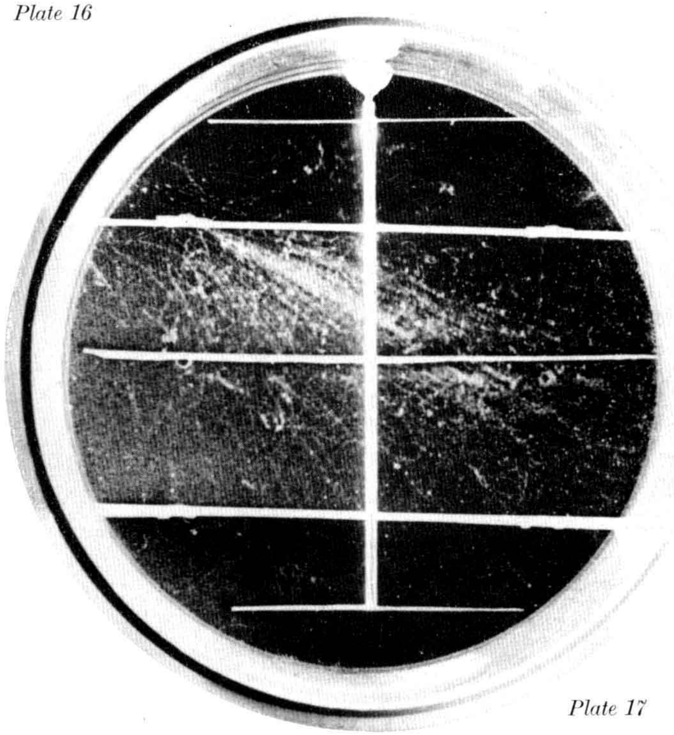

Plate 17

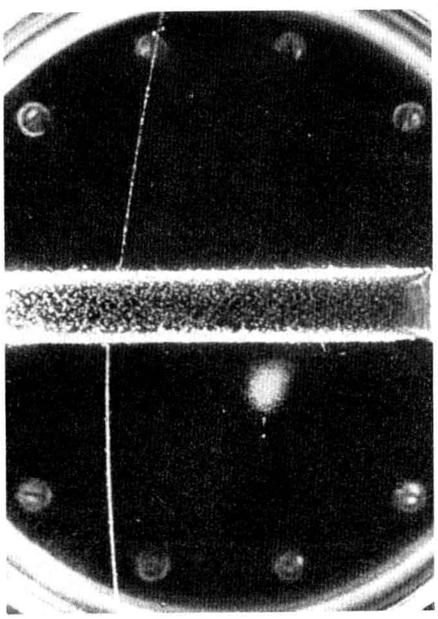

Plate 18

Plate 18. R. C. Jopson, Pasadena. (Unpublished.)

A chamber, 15 cm. diameter × 3 cm. usable depth, is controlled by a proportional counter with a 65 mil. aluminium wall inside the chamber.

The photograph shows a slow proton of momentum 225 MeV/c. above the counter and 95 MeV/c. below.