NEW TYPES OF NUCLEAR DISINTEGRATIONS

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SUMMARY

Special photographic emulsions developed to record the tracks of charged particles have been exposed to cosmic rays at high altitudes by being carried in aircraft on trans-Atlantic flights. Total exposure times of more than 200 hours above 10,000 feet, with more than half being above 15,000 feet, were achieved.

Microscopic examination of the plates disclosed a large number of nuclear disintegrations produced by cosmic rays. Detailed study of these disintegrations revealed several types not previously reported.

Mesons were observed which produced at the end of their range a single proton, a single alpha particle, or one or more of each, and in one case, a secondary meson. Mesons were found among the particles of nuclear disintegrations.

Other phenomena included the fast neutron disintegration of boron, the ejection of an alpha and a proton from nuclei, a "star" of 26 particles, and proton tracks with energies greater than 40 mev.

FOREWORD AND ACKNOWLEDGEMENTS

The investigations reported here were the result of an interest in the application of the newly-developed photographic emulsions to nuclear physics problems. Cosmic ray data was sought in the hope of getting information on nuclear disintegrations which would complement, supplement or confirm that which could be obtained in the laboratory.

Consideration was given to exposures on mountains or by balloon ascents, but neither could be carried out conveniently or at once. Exposure by flights to high altitude in aircraft seemed impracticable, until it was realized that scheduled commercial flights were carried out at high altitude whenever they were of sufficient duration, and that they were frequent enough that adequate exposure times at altitudes greater than 10,000 feet might be secured in a few weeks of scheduled trips. Exposure of plates in this way was arranged for and successfully carried out.

On examination of the plates several new types of nuclear disintegrations were found. These have been described in Section VA and VB. Those which are believed to be new and described and illustrated for the first time are VA, 1, 2, 3 and 6, and VB, 1, 2 and 7.

In addition, the confirmation of the primary and secondary meson (VA,4), the information on mesons from stars (VA,7), the study of 3, 4 and 5-pronged stars entirely in the emulsion, (VB, 3, 4 and 5),and the photomicrograph and data on the very large 'star' (VB,6), and the statistical data on 'star' frequency (Appendix V) are believed to be contributions to knowledge.

The small 'stars' formed by a meson from another disintegration (VA,5) and the meson events of VA,7 are types of event previously published and illustrated, but are included here since events of this type are still very rare and the photomicrographs and data may still make some contribution to an understanding of meson-produced disruptions.

Some items of equipment which helped in securing the data and producing the photomicrographs and which may be cited as original, though minor, contributions to knowledge, are the developing machine (Fig. 3) and the film holders for photomicrography.

The co-operation of a number of persons has been an essential element in this work and it is a pleasure to acknowledge their assistance here.

The observations reported here could not have been secured without the interest and encouragement of Dr. W. J. Henderson of the Physics Division, National Research Laboratories, who acted as my immediate supervisor. His complete co-operation in putting materials, apparatus and technical assistants at my disposal as needed is greatly appreciated.

The guidance and advice of Dr. J. S. Foster, Director of the Radiation Laboratory, McGill University, with whose ported here as the individuals mentioned above, Dr. A. Norman Shaw, has contributed to it through the many kindnesses and the unfailing encouragement he has extended to me during the past two years.

TABLE OF CONTENTS

TABLE OF CONTENTS (cont'd)

NEW TYPES OF NUCLEAR DISINTEGRATIONS

I INTRODUCTION

The new types of nuclear disintegrations which will be described here were observed in the emulsion of special types of photographic plates which have been carried in aircraft at high altitudes.

A charged particle travelling through a photographic emulsion affects some of the silver grains through which it passes leaving a track analogous to the column of ions which the particle leaves in passing through the gas of a cloud chamber. On development the path of the particle in the emulsion becomes visible as a series of developed grains, or a track. The heavier or more heavily charged particles leave heavier tracks. Since the density of the photographic emulsion is much greater than that of the air or other gaseous mixture in the cloud chamber, the length of the tracks is correspondingly shorter, and they must be observed under a microscope. For emulsions now in use the stopping power of the emulsion is approximately 1800 times greater than that of air so that a track 10 cm long in a cloud chamber is about 55 microns long in the emulsion. Thus an area 20 by 60 mm on a photographic plate with an emulsion 100 microns thick, is equivalent to a cloud chamber 36 metres by 108 metres by 18 cm. deep. The emulsion is continuously sensitive and because of its extent and thickness will contain completely tracks which are much too long to be entirely within a cloud chamber, or which are sloping steeply and would pass out of the illuminated volume of the cloud chamber.

The ordinary photographic emulsions used at first had some disadvantages to offset these valuable properties. The silver halide grains in the emulsion were very irregular in size, some being very large while others were near the limit of visibility, and they were embedded in relatively large quantities of gelatin and hence were spaced far apart; as a result the tracks, particularly when not in the horizontal plane, were often hard to follow due to the wide and irregular gaps between successive grains; ranges of particles of like energies showed considerable variations and identification of the tracks due to different kinds of particles was uncertain. Identification was further complicated by rapid fading of the tracks; old alpha tracks soon became similar in appearances to more recently formed proton tracks. These disadvantages have now been largely overcome by the production of emulsions in which the grains are smaller and more uniform; the gelatin content is low so that the grains are close together, and the sensitivity to charged particles has been increased while sensitivity to light has been decreased. Fading, while not eliminated, has been reduced so that exposures of some weeks duration are practical.

The development of the photographic emulsion technique up to the end of 1940 has been very well covered in a review article by Shapiro (S3). An article by Yagoda (Y4) describes later developments and applications. Articles by Powell (P16) and Demers (D3) describe the properties and advantages of the new concentrated emulsions. Range-energy relations for the Ilford emulsions are given in an article by Lattes, Fowler and Cuer and graphs based on these are given in Appendix II. A list of articles in this field since 1936 is given in the bibliography (Appendix I).

Observations of cosmic ray phenomena were made by Wilkins (1) and by Rumbaugh and Locher (2) in 1936 and by Blau and Wambacher (B4) and by Schopper (S5) in 1937. Blau and Wambacher in 1937 observed 'stars' or nuclear disintegrations produced by cosmic rays in the photographic emulsion. Detailed examination of these and identification of their parts was made difficult by the poor emulsions then in use. Cosmic ray experiments were interrupted by the war but were resumed about 1945 and Powell and his collaborators at Bristol have been very active and have published a number of papers on cosmic ray induced phenomena obtained in plates exposed at altitudes up to 16000 feet. A few balloon flights have been made but exposure

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(1) Wilkins, T.R.; Phys. Rev. 49, 403 (1936).

(2) Rumbaugh, L.H. and Locher, G.L.; Phys. Rev. 49, 889 (1936)

times secured in this way have been very short so far. (S1) (S2)

Photographic emulsions may be used for the study of nuclear disintegrations which take place in material adjacent to the emulsion, or which take place in the material of the emulsion itself. In the first case, any material may be used which can be placed near the plate in a vacuum or in contact with it and from which charged particles are ejected whose nature, energy and direction may be determined from their tracks in the emulsion. In the second case, the elements disintegrating may be those normally found in the emulsion or may be other elements which have been deliberately added to the emulsion. A number of such "loaded" emulsions are now available and were utilized in these experiments. The usual loadings are lithium, beryllium and boron. Bismuth loaded emulsions have recently become available and deuterium loaded emulsions have been prepared. When emulsions are loaded with elements such as lithium or boron it should not be forgotten that these are added in the form of compounds and the other elements in these compounds constitute an inadvertent loading of the emulsion. The effect of this can be seen by examining the chemical composition of various emulsions as supplied by Ilford and set out in Appendix III.

An increasing number of problems of nuclear physics are being undertaken with the special nuclear research emulsions now available, a few of these experiments are: the scattering of protons by protons, (C3); determination of the range of alpha particles from samarium, (C9); identification of the 4n+1 radioactive series, (E1); studies of nuclear fission (B8), (B9), (G4), (H5); measurement of neutron energy spectra, (R1); photo disintegration of deuterium, (G2); fine structure of the alpha particles of polonium, (C5). A more complete list of these problems is given in the papers already mentioned and in other papers by Powell (P13) (P15).

Both types of application, to cosmic ray studies, and to research in the laboratory, were contemplated when work with photographic plates was begun. Most of the emphasis so far has been on cosmic ray phenomena and it is the results in this field that will be reported here, although brief reference will be made to laboratory experiments in the fast neutron disintegration of boron and the photo-disintegration of deuterium.

The technique developed for the handling, exposing and examining of plates is discussed first, followed by a description of a number of new phenomena found in plates exposed to cosmic rays.

I. DEVELOPMENT OF TECHNIQUE

(a) Preliminary Experiments

When it was first decided to undertake photographic emulsion work very little information of any kind was available. The new types of plates had just become generally available and even the manufacturers did not have the answers to a number of questions. A number of preliminary experiments were undertaken to gain familiarity with the technique and to find answers to some of the questions which had arisen. Some of the more important of these preliminary experiments will be reported here.

The plate size to be used was chosen as 25 mm. by 75 mm. since this appeared to be a convenient size for use on the standard microscope stage and to store in readily available slide boxes. A few dozen of each of the available emulsions were ordered in thickness of 50 and 100μ.* Subsequent experience confirmed that this was a convenient size and indicated that a thickness of 100μ or more was desirable.

After nuclear research plates had been ordered from Kodak and Ilford, some Ilford halftone plates, the kind used by the early experimenters, which were on hand were exposed to alpha particles from a radium-bearing foil. Tracks were produced in the emulsion but it was found very difficult to see them since the emulsion was thin and only glancing-angle tracks had enough grains to make

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* = micron or microns

them visible, and even in these the grains were far apart. The principal use of the experiment was to illustrate the difficulties met by the early workers.

Some lithium-loaded plates were included in the first nuclear research emulsions to arrive and these were exposed to neutrons from a radium-beryllium neutron source. An overnight exposure of plates at 20 cm. from the 500 mg. source enclosed in 2.5 cm. of lead and 10 cm. of paraffin, produced a considerable darkening of the plates due to the gamma rays and produced a few disintegrations of Li^6 into an alpha particle and a triton according to the reaction

$$_3Li^6 + {_0n^1} \longrightarrow {_2He^4} + {_1H^3} + Q$$

Q = 4.9 mev. Slow neutrons were responsible for this reaction, so the alpha and the triton tracks were in the same straight line.

By arrangement with D. Brunton at the Atomic Energy Project, a few plates loaded with lithium and boron were exposed to a large flux of thermal neutrons. A very large number of Li^6 disintegrations were produced and measurements were made on some of these. Only those tracks which were parallel to the surface and entirely within the emulsion were chosen and the total length of the two tracks was measured. The point of origin of the two parts could not be determined since the H^3 track and the He^4 track were in the same straight line and were not distinguishably different in grain density. A graph of the number of tracks versus total range is given in Fig. 1. This shows a peak at about 34.3 div. or 42.8 .

When this plate was examined with a low or medium power microscope objective, it was apparent that the tracks were not uniformly distributed but tended to form clusters. This was taken to indicate that the lithium loading in the emulsion was not uniformly distributed. A pair of photographs illustrating this are shown in Fig. 2.

It was hoped to examine one or more boron loaded plates for the disintegration

$$_2B^{10} + {}_0n^1 \rightarrow {}_2He^4 + {}_3Li^7$$

Some of the lithium atoms are produced in an excited state and therefore such disintegrations show a smaller combined range for the two particles. Unfortunately all the emulsion peeled off the boron-loaded plates while in the developer. This happened to all the boron-loaded emulsions first received. Correspondence with Ilford Ltd. led to an improved composition in later emulsions and they no longer peel.

Proton tracks were produced in the emulsions with the radium-beryllium neutron source mentioned above. Hydrogen atoms in the emulsions, recoiling from collisions with fast neutrons, left proton tracks of considerable length. An exposure of three hours at 10 cm from the source, with 8 cm of lead intervening to cut down the gamma rays, produced a convenient number of recoil protons without making the background on the plate too high. Proton tracks produced in this way were utilized in the experiments of the effects of low temperatures and on development technique.

Since plates to be used for exposure to cosmic rays were to be taken to high altitudes and might be at low temperatures, and since no information on the effect of low temperature on the sensitivity of the plates, or on the adhesion of the emulsion to the glass, could be obtained, some experiments to get this information were done.

Plates were exposed to fast neutrons at 70°F, -10°F, -40°F and -58°F, developed and examined. It was apparent that differences, if present, were slight. Exposures were made again at 70°F and -58°F, other conditions being carefully maintained identical and the resulting plates were examined in detail. The number of proton tracks found in equal areas of plates, these areas being the same distance from the neutron source, was determined, as were also the optical densities of the plates and the number of grains in given areas in the field of view at two different depths below the surface of the emulsions. The plates were examined for loosening of the emulsion due to low temperature.

It was found that the 70°F plates showed somewhat higher optical densities and higher background grain counts, while the -58°F plates showed a greater number of proton tracks in a given area. The differences were not great in view of the statistical fluctuations which may be expected in the figures, and it was considered that any changes in sensitivity from 70°F to -58°F were not large enough to be a cause for concern on cosmic ray exposures. There seemed to be little or no advantage in respect to sensitivity in trying to maintain the plates at normal room temperatures. Comparative figures for two plates of the most sensitive type of emulsion, B2, are given in the table below.

TABLE I

Temperature	70°F	-58°F
Plate No.	B2-127	B2-128
No. of grains - 5μ below surface	535	460
- 25μ below surface	310	270
No. of proton tracks	42	57
Optical density	0.71	0.67

The low temperature did not appear to have any very harmful effect on the emulsion or its adherence to the glass plate. This was important since it established that the peeling of boron-loaded plates, mentioned earlier, was not due to any low temperature encountered en route by air from Ilford Ltd. and since it established that plates could be used at low temperatures without mechanical damage to the emulsions.

(b) Development Techniques

Some work was done on development technique. Hand-rocking of the trays in which development and fixing of the plates was done and was felt to be unsatisfactory since it was non-uniform and required too much attention; a machine was devised to rock the trays uniformly and constantly (Fig. 3). Kodak D-19 developer was chosen as being similar to Ilford ID-19 and was used diluted, one part of developer being mixed with two parts of water, as recommended by Ilford. To find the most suitable time of development, plates with emulsions 100 microns thick which had been exposed to fast neutrons, as described above, were developed for 5, 10, 15, 20 and 25 minutes, then examined in the same way as those used for the comparison of room- and low-temperature exposures. The five-minute development was definitely too short, the 10-, 15- and 20-minute developments seemed acceptable and the 25-minute development was too long since it made difficult discrimination between alpha and proton tracks. The 15-minute development seemed to be the best choice and was adopted.

A uniform developing procedure was used throughout the work reported here. As mentioned above, Kodak D-19 developer diluted one part of developer to two parts of water was used. A measured amount, 120 ml., was put in each tray. The trays were of glass, about 10 cm by 15 cm, with two ridges on the bottom on which the plates rested, emulsion side up. Not more than four plates were developed in one tray at a time; these were well spaced and the two inner plates were interchanged with the end ones once or more during development. The trays were rocked mechanically during development at a speed of about 15 cycles per minute, and this, in conjunction with the spacing of plates, the flow of developer under as well as over them, the interchange of center and end plates and the fixed amount of developer, ensured adequate and uniform contact of the developer with the plates. The temperature of the developer was held between 65°F and 68°F and the plates were left in it for 15 minutes. At the end of this period the plates were transferred to an acid stop bath (2% acetic acid) for 5 minutes, and were then fixed with Kodak Liquid Fixer. The fixer was renewed after the first 10 minutes and again after the next 15 minutes. The plates were fixed in glass trays similar to those used for development and these too were rocked mechanically during fixing. After fixing for 1.5 times the time required to clear, the plates were washed, dried and filed in microscope slide boxes.

(c) Examination Methods

A monocular microscope was used at first for the examination of plates but this was quickly abandoned. It was found too much of a strain for persons unaccustomed to a monocular microscope to use it continuously for the type of observation required here.

A binocular microscope was substituted and it was found quite feasible to carry on continuous examinations for one or more hours a day without undue fatigue or eye-strain. In addition, particularly with low power objectives, the binocular microscope seemed to introduce a slight stereoscopic effect which was quite helpful in searching. All of the four microscopes eventually used in searching and studying plates were binocular.

Various combinations of objective and oculars were tried for searching the plates and for studying the cosmic ray events found. For searching the best balance of magnification, field of view and depth of focus was secured with an objective of about 8 mm. focal length (20x-24x) and with oculars of 12x or 15x. The 16 mm. objective, (12x), while it had a good depth of focus and covered a large area of emulsion, did not provide adequate magnification or resolution. The 4 mm. objective (45x) when used with 5x or 6x oculars had about the same field of view as the preferred combination and had better resolution but was much less convenient to use since it had a smaller depth of focus and a shorter working distance, it required a cover glass and needed to be accurately adjusted to cover glass thickness and it required optimum illumination. The smaller depth of focus meant that it must be rocked up and down more to see the whole of the relatively thick emulsion; the smaller working distance meant that it was easier to touch the emulsion with the lens inadvertently; the two together, combined with the fact that the emulsion was usually more or less covered with a thin layer of oil due to frequent resort to the oil immersion lens, meant that the front surface of this lens required frequent cleaning. For areas of the size of those scanned on the 25 mm. x 75 mm. plates, i.e. 20 mm. x 60 mm., it was inconvenient to have to apply a cover glass, though of course simple enough to adjust the lens to the appropriate thickness of glass once it was applied. Unless the illumination was well adjusted it was very easy to get glare and lack of image contrast with the 4 mm. lens. A 3.75 mm. oil immersion fluorite lens was found fairly satisfactory for searching, using 5x or 6x oculars; being oil immersed the worse disadvantages of the 4 mm. lens were eliminated. For studying events in detail, the 2 mm. objective (90x) or the 1.5 mm. objective (114x) was used, since the numerical aperture and hence the resolution were the best obtainable. Each of these objectives, and the 3 mm. oil immersed objective was rejected as being uneconomical of time for searching the plate because of the large amount of running up and down of the lens required and because in each case with the oculars available, the field of view was too small.

Both achromatic and apochromatic objectives, with appropriate eyepieces, were used. The apochromatic systems were preferred since for a given focal length or magnification a higher numerical aperture can be secured with them(1) and since oculars of higher magnification can be used in apochromatic systems(2).

Kohler illumination, using a lamp with a focussing lens and an iris diaphragm was found most satisfactory. Control of intensity through a lamp current control or through neutral filters or with both, was found necessary. A green filter was usually used in the beam, as a green background on the field of view seemed to be less strain on the eyes than a white or blue one.

The mechanical construction of the microscope was also important. The location of events was recorded by the co-ordinates of the graduated mechanical stage when the event was centered in the field of view. It was necessary that the vertical and transverse motions of the stage be smooth and easily operated so that a particular grain in the emulsion could easily be brought to

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(1) 8 mm achromat N.A. = 0.45 2 mm achromat N.A. = 1.25
8 mm apochromat N.A. = 0.65 2 mm apochromat N.A. = 1.32

(2) Shillaber, C.P., Photomicrography in Theory and Practice; J. Wiley & Sons, N.Y. (1944)

any particular part of the field of view. A smoothly operating stage, with which very small displacements could be accurately made, was also necessary in measuring the length of tracks with an eyepiece scale, or in counting grains. For some purposes the fine adjustment was used as a depth gauge and in such cases a fine control dial with graduations accurately corresponding to one micron per division throughout the whole range of motion was desired. Since the graduations were accurate only in the center of the range for some of the microscopes, depth measurements were always made with the fine control in the center of its travel. Ease of adjustment and centering of the condenser was also essential.

The requirements of the microscopes used for this purpose may be summed up by saying that the very finest available in optical and mechanical construction is none too good.

(d) Projection Equipment

It was felt that there might be some advantages in examining plates with a micro-projector where the observer looked at the projected image of the field of view rather than into the microscope, and accordingly a considerable effort was put into the development of such an apparatus.

The principal problem was illumination; it was hard to get enough light on the screen and to get it uniform. After preliminary trials with ordinary microscope lamps had failed to produce sufficiently bright images, a carbon arc was tried and gave adequate illumination, but had serious disadvantages. The large amount of stray light from it lit up the room and reduced the contrast in the image on the screen; to eliminate the stray light a light-tight housing was necessary but this had to be rather large and cumbersom to permit ventilation. Another disadvantage of the carbon arc was the amount of attention required to replace the carbons as they burned down and to keep them on proper adjustment, a 'Zirconarc'[1] was tried and was found to be very satisfactory; no light-tight housing was needed and the brightness of the image was adequate.

Very careful alignment of the optical system of the microscope was found necessary for good results in projection.

Once the projection system was working, remote control of the principal motion was added. Slow speed reversible motors were coupled through flexible shafts to the vertical fine-motion of the microscope and to the horizontal or traverse motion of the mechanical stage. These

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(1) Fish Schurman Corp., New York, N.Y.

motors were each controlled from a pair of push buttons in parallel with a three-positioned lever switch, mounted on a small panel and linked to the motor with flexible cable. The operator, holding the control panel on her lap, and watching the image on the screen, could move the plate in either direction transversely and at the same time could move the focal plane up and down through the emulsion by pressing the appropriate push button momentarily for a small change of position, or by pushing the lever switch up or down from its central neutral position for continuous motion.

Several motors were available and various combinations of motor speed were tried. For the Zeiss microscope used a good combination was a speed of 1 r.p.m. for the transverse motion and 6 r.p.m. for the vertical motion.

At first the image was projected horizontally, using a silvered prism, from the top of the microscope tube to a vertical ground-glass screen in front of the operator and between her and the microscope. This was not found as satisfactory as a white, fine-grained paper on a vertical board on the opposite side of the microscope to the operator. The ground glass had too coarse a grain and gave too poor an image contrast for this use. When the image on the vertical screen was the right size, it was inconveniently far away, so a front-surfaced mirror was introduced to reflect the horizontal cone of light from the prism downward onto a horizontal screen on the table top. This proved to be very satisfactory and was adopted.

Although the projection system finally evolved was very satisfactory optically and mechanically, it was used very little for the examination of plates. One reason for this was that the observer watching the image on the screen had no sense of depth perception such as appeared to exist in direct binocular observation; this was felt to be a real disadvantage. A second reason for not making greater use of the projection microscope for examination was that the observer on the projection microscope had to work in a dark room, and since there was only one such outfit, had to work alone, and did not like either condition. All the observers preferred to work in a lighted room where recording of observations was more easily done, and all preferred to work in company. This type of work, with long continuous periods of close observation required, is both tedious and exacting and the observers comfort and happiness had to be taken into account. The third and most important reason was that the optical system was found to be excellent for photomicrography of events in the emulsion and the projection microscope was soon utilized full time for this.

It appeared probable that the motor-driven remote-controlled scanning arrangements might be utilized advantageously on a binocular microscope used for direct observation. This was not tried as the probable gain in speed and convenience did not appear attractive enough to offset the time required in fitting it to the microscope and adjusting it.

(e) Photomicrography of events

Good photomicrographs of nuclear disintegrations in photographic emulsions were hard to get. The tracks of the ejected particles were only infrequently aligned with the focal plane of the objectives; usually they slanted more or less steeply in the emulsion. Since the grains were small, of the order of 0.2 to 0.4 microns in diameter, the maximum resolution was needed and this meant that the short focus, high magnification objectives with their large numerical aperture were required. These objectives have a very small depth of focus so that for a slanted track, only a short length, a few grains, could be brought into focus at one time. The grain spacing of energetic tracks was quite large and it was often very difficult to follow such a track under the highest magnification. Many of the tracks which were photographed extended for several hundred microns and were sloped in the emulsion so that only 5 or 10 microns were in focus at any one time.

A fairly successful solution to to this problem was found by using the projection system developed for searching and a special film holder with two slides, with which a strip of film could be exposed a few millimetres at a time. This film holder is described in Appendix IV.

It was found difficult to get uniform exposures and this was traced to decrease in light intensity from the center of the field outwards and the variations in transmitted intensity from one plate to another and from one part of a plate to another. A photoelectric light-intensity meter was built and used to monitor light intensities and to adjust exposure times. With this,reasonably uniform results were secured.

The photographs were made on 'Kodalith Thin Base Ortho Film', since this had fine grain and high contrast and was readily available. Contact prints were made and from these a mosaic of the track being studied was assembled on a large sheet of heavy white cardboard. The completed mosaic was photographed and final prints made. This phase of the work was very exacting and time-consuming since a single mosaic may require several strips of film each with from five to twenty exposures on it. I am greatly indebted to Mr. F. I. Morton and to Dr. E. Pickup for their patience and skill in photographing the events and constructing the mosaics with which this thesis is illustrated.

A photograph of the projection apparatus is shown in Fig. 4.

III EXPOSURE OF PLATES

Inquiries were made of the RCAF as to the possibility of having plates carried to high altitudes on test flights or on aerial survey flights. It was found that at the time this request was made no flightsof the kind required were being made.

Since commercial trans-atlantic flights were in regular operation,letters were written to Trans-Canada Airlines and to British Overseas Airways Corporation asking for data on the duration, frequency and altitude of trans-Atlantic flights and enquiring if it would be possible to have plates carried. Both firms were very co-operative; T.C.A. however was not at that time flying pressurized aircraft, so normally did not fly above 8000 feet; B.O.A.C. on the other hand,with pressurized aircraft,usually flew above 10,000 feet and the frequency and duration of the flights looked very favourable. A visit was made to Dorval and arrangements to have the plates carried were completed. At the same time the experiment was discussed with F/L Rood of T.C.A. and he suggested that when they began to use pressurized aircraft (North Stars) in a few months, they would be glad to carry plates. This offer was never taken up since it was found that more plates could be exposed through B.O.A.C. than could be examined.

Inquiries were also made of the Smithsonian Institute as to the possibility of having plates exposed at their astro-physical station in Chile. Their reply was that at the present time this was not feasible due to shortage of staff and difficulty in getting material into and out of Chile.

At the time the original arrangements were made, it was thought that it would be necessary to keep the plates at a uniform temperature and it was therefore decided that thermos bottles would be used as plate carriers. Subsequent experiments, previously mentioned, showed that if any loss of sensitivity occurred it was not serious, but by that time holders for thermos bottles had been constructed and mounted in a plane so they were retained.

The aircraft on which plates in these thermos bottles were carried, was on regular service between Canada and the U.K. and Canada and Bermuda via the U.S.A., and at each landing inspection by Customs Officers was made. To avoid difficulty, each bottle was drilled and the bottle and top locked shut with a wire, both ends of which was embedded in a tray of sealing wax, which was stamped with the official seal of the Research Council. A typewritten letter explaining the purpose of the bottles was attached to the outside of each, under a celluloid cover. Arrangements were made with the National Research Council Liaison Office in London to have the arrangement explained to the

U.K. Customs and approved by them. No advance arrangements were made with U.S. or Bermuda Customs but no difficulties have yet arisen; the note on the bottles was apparently sufficient.

A photo of one of the bottles as prepared for despatch to B.O.A.C. is given in Fig. 5.

Two bottles were used, one marked "vertical" and carried upright, the other marked "horizontal" and carried in its holder in that position.

The bottles were held on wooden holders constructed by B.O.A.C. and fastened near the top of the vertical aluminum bulkhead, separating the crew compartment from the passenger cabin near the front of the aircraft.

For the first trial exposure, the plates were unpacked and rewrapped individually in groups of two or three and were slid into the glass thermos, surrounded by absorbent cotton to hold them in place. After the first exposure the glass thermos was removed to give more room inside the cylindrical case. The first plates showed signs that they might have been contaminated with radioactive material when they were rewrapped, so for all subsequent work plates were put in groups of four, in their original paper wrapping, i.e. untouched, into the cardboard boxes in which they came from the manufacturer and these boxes were wrapped in cotton and placed in the bottles with the emulsion having the desired vertical or horizontal orientation.

The first groups of plates were sent to Dorval by railway express and returned in the sameway. This was found very unsatisfactory as they were in transit each way for four or five days. An arrangement was made with T.C.A. whereby plates taken off the B.O.A.C. plane at Dorval were put on the next T.C.A. plane to Ottawa and were picked up at the airport by an employee of the National Research Laboratories. In this way plates could be in the laboratory on the same day and only a few hours after being taken off the trans-Atlantic plane.

The time-altitude data on exposures was prepared at first by the B.O.A.C. Technical Analysis Division staff in the form of a graph showing height against time. This entailed a great deal of work on the part of the B.O.A.C. staff, so subsequent data was obtained from the flight log-book in the course of a visit.

In addition to those exposed to cosmic rays, a number of plates were placed in a beam of fast neutrons produced by the bombardment of lithium by deuteron ions of 600 kv energy.

Three attempts were made to produce photo-disintegration of deuterium with high energy gamma rays. The deuterium loaded plates were specially prepared by Ilford from a sample of sodium tri-deutero-acetate produced by

Dr. Leitch of the Chemistry Division of the National Research Laboratories. The high energy gamma rays were produced by proton bombardment of a fused sodium fluoride target. In the last attempt an average current of about 80 micro-amperes of unseparated ions was used and the exposure period was about 4 hours with the deuterium-loaded plates less than three centimetres from the target. A search of 5 square centimetres failed to reveal a single proton track which could be ascribed with certainty to the photo-disintegration of deuterium.

IV. EXAMINATION OF PLATES

The examination of plates was divided into two parts; a preliminary search to locate all phenomena of interest, and a further detailed analysis of the more interesting of the events.

The preliminary search was a systematic survey of the central portion of each plate. The plates used were 25 mm. by 75 mm. and the area searched was 20 mm. by 60 mm. As mentioned earlier, an 8 mm. objective was used with a pair of 12x or 15x oculars, the combination having an overall magnification of about 300 times. The plate was scanned by moving it horizontally under the objective for 60 mm., displacing it a distance about equal to the width of the field of view with the vertical motion of the mechanical stage, then moving it back horizontally to the initial point, and so on. Whenever an event was discovered in the field of view, the point of origin of the observed tracks was brought to the center of the field of view, and the horizontal and vertical co-ordinates of the stage were recorded. A diagram was made on the record sheet and the event was moved back to its original position in the field of view and the searching was continued along the same horizontal path. A typical first and second page of the searching record is illustrated in a photograph in Appendix VI.

After the preliminary search was completed, some of the events found were analysed. In general, this analysis was carried out according to the number of tracks in the event, all events with two tracks being examined first, then all with three tracks, and so on. The two- and three-pronged cosmic stars were analysed in all plates, and in a few the analysis was carried as far as seven-pronged stars. A few larger stars were examined.

The purpose of the analysis was to ascertain where possible, the identity, energy and direction of each of the particles participating in the disintegration, and to see if any conclusions could be drawn as to the nature of the disintegrating nucleus, and as to the particle or agent causing the disintegration. Two typical pages from the analysis sheets are shown in a photograph in Appendix VI.

After the methods of searching and recording the results had been devised almost the whole responsibility for and conduct of the searching was assumed by the three technicians, Joan and Shirley Young and Beverley Mear. They were intelligent and interested and the large volume of emulsion searched is a measure of their diligence and efficiency.

The analysis was also carried on by these observers, once the method had been evolved, but with considerably less responsibility, since every event of any particular interest

interest was also examined by the author and many of them were examined by more than one of the observers.

In analysis of the events the most important things to be settled were the identity of the particle causing a particular track and its direction of motion. Only after the kinds of particles were known, and whether each was moving towards the 'origin' or 'vertex' or away from it, could the nature of the disintegration be considered.

The nature of the particle was determined from the weight of the track left behind, and from the number and frequency of the deflections which it suffered. The weight of the track or the number of grains per unit length was dependent on the mass, charge, and energy of the particle which produced and also on the age of the track and its slant in the emulsion. The tracks were heavier for more massive and more highly charged particles, but the greater the energy or velocity the farther apart were the grains and the lighter was the track. The older a track was before development of the plate, the lighter it appeared, since some of the grains made developable by passage of the particles seemed to lose this property with time and older tracks from any one kind of particle appeared faded. A track which slanted through the emulsion had a larger apparent grain density than one which was horizontal; since the emulsion decreased in thickness by a factor of about two or more in processing, it had a real grain density greater than that of a track of the same kind and age in the horizontal plane,by an amount which depended on the steepness of the slant.

Alpha particle tracks rarely showed deflections and when they did there was usually only one in a track and that one was often through a considerable angle. Proton tracks showed deflections much more frequently and these were often small angle deflections so that the track appeared to curve. Mesons showed the most scattering and the tracks often appeared quite curved, but even these could occasionally be almost straight.

Counting of the grains in successive lengths of track and comparison of these counts with those of tracks whose identity was better established was often necessary to secure reasonably sure identification.

Identification, even after grain counts were available, could not always be positive, since proton tracks of different weights due to ${}_1H^1$, ${}_1H^2$, and ${}_1H^3$ were possible and since fading could have occurred. The emulsions also were found to have 'islands' or areas where grain counts were abnormally low. In loaded emulsions these may have corresponded to areas of very high or low concentration of the loading material as mentioned and illustrated earlier.

Detailed statistics of the plates searched and the number and kinds of events found are given in Appendix V, so only the number of stars found, 1092, and the volume, 3.31 cc, and area, 359 sq.cm., of the plates searched, will be mentioned here.

RESULTS

The state of knowledge of meson events in photographic emulsions at the time this is written may be summarized briefly as follows:

(a) Meson tracks have been observed which came to an end in the emulsion with no visible secondary tracks. These mesons were apparently absorbed by a nucleus; any products of this reaction were either uncharged or were too energetic to leave visible traces in the emulsion. These may include both positive and negative mesons.

(b) Meson tracks have been observed which end in the emulsion in a more or less spectacular nuclear disintegration.

(c) Meson tracks which end with the production of secondary mesons have been observed. The secondary mesons are believed to be lighter, with masses of about 200 m_e* as compared to masses of about 300 m_e for the primary mesons. The secondary mesons do not produce any disintegration.

(d) Mesons have been observed to come from nuclear disintegrations; some of these produce further disintegrations, others do not.

(e) Mesons have been produced artificially at the Radiation Laboratory, University of California, (G1). These are both positive and negative, with masses of about 300 m_e; the positive mesons produce secondary mesons and the negative mesons, in about 2/3 of the cases, produce disintegrations.

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*m_e = mass of the electron

In the work reported here, the plates were searched primarily for cosmic stars where a cosmic star was defined as any event with six or more tracks, or any event with two or more tracks, at least one of which was more than 50 microns long.* All cosmic ray stars were examined for the presence of meson tracks. Single meson tracks were not specifically searched for, although a few were noticed and recorded.

In analysis, particular attention was paid to events with two, three and four tracks, since it was felt that these had been largely overlooked because of the interest in mesons and in the more spectacular many-particle nuclear disintegrations. Furthermore, it was felt that with these events, there was a good chance that a number of examples with all tracks ending in the emulsion could be found and for these a fairly sure identification of the particles might be made. It was hoped that information on the kinds of disintegrating nuclei and the cause of the disintegration might be obtained.

For convenience in discussing them, the events observed will be divided into two groups, those which were caused by mesons or which produced them, and those in which mesons were not visibly involved.

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*'Stars' of five tracks or less, where the tracks are less than 50 microns long are usually due to the presence in the emulsion of very minute amounts of radium and thorium.

A. Phenomena Involving Mesons.

1. Meson-Alpha Event.

Two cases were observed in which an alpha particle appeared to have been ejected from a nucleus by a meson at the end of its range.

The first of these cases* is illustrated in Figure 6. A proton track in the same plate is illustrated alongside for comparison.

The meson track was followed back for a distance of 1250 microns to the point where it entered the emulsion from the air. Throughout this long path, and particularly near the end, it showed considerable scattering. It was identified as a meson by this scattering and by the low grain density near the end of its range. The grain count for the meson in comparison with the average grain count for four protons in the same plate is given in Table II, below.

TABLE II

Residual range (microns)	0	25	50	75	100	125	150
Meson grain count	0	21	50	80	104	127	139
Proton grain count (av.)	0	39	73	103	130	159	183

The alpha track was completely in the emulsion and identification was made from its appearance. At the end the grains were too close together to be counted; it seemed to be about the same as alpha tracks found in radium and thorium disintegrations in the emulsion or found in the multi-pronged cosmic stars.

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*Plate C2L98, A2pcs, p.1.

The length of the alpha track was 162 microns, this corresponds to an energy of 18.0 mev.

In the second event of this kind* (shown in Fig. 7) neither track was entirely in the emulsion. The mesons entered from the glass, and travelled 75 microns through the emulsion before coming to rest. The ejected alpha particle stayed in the emulsion for 139 microns before emerging through the surface into the air.

The meson was identified by its scattering and by its low grain count. The grain count from the end back along the track is given in Table III below in comparison with the average of four protons in the same emulsions.

TABLE III

Residual range (microns)	0	25	50	75
Meson grain count	0	25	46	63
Proton grain count (av.)	0	39	73	104

The alpha particle was identified as such from the appearance and grain count. The last part of the track before it passed through the surface of the emulsion was too heavy to be a proton track (92 grains in 50 microns) and in fact corresponded to the weight of an alpha track near the end of its range.

It might be suggested that the track could be due to a particle heavier than an alpha particle of which only the first and lightest part can be seen, but this is unlikely

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*Plate C2B157, A2pcs.; p.11

since no track heavier than that of an alpha particle, of length as great as this, has been seen; further, the rate of change of grain density corresponds to that seen in alpha tracks.

This track corresponds to at least 16.5 mev of energy. Since the track appears to be nearing the end of its range it may be conjectured that its length and energy would have been similar to the first one had it remained in the emulsion.

A rather surprising feature of these two reactions is that no recoil track or tracks were seen in either case. From this it may be argued that the alpha particle was ejected from one of the heavier nuclei in the emulsion, i.e. from a silver, bromine, iodine or sulphur nucleus.

The light elements which the two emulsions have in common are oxygen, nitrogen, carbon and hydrogen. If the alpha were ejected from the oxygen, carbon or nitrogen, the residual nucleus, if it did not break up, would have from 6 to 9 mev* of energy and would almost certainly have a recoil track. If the nucleus broke up, the energy would be distributed among the parts and some of them would leave visible tracks. No recoils were seen so it may be assumed that the alpha did not come from a light element.

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*In recoil. $p_1 = p_2$, i.e. $2m_1E_1 = 2m_2E_2$ or $M_1E_1 = M_2E_2$ or $\frac{E_2}{E_1} = \frac{M_1}{M_2}$

This argument is further strengthened if we assume that the energy available is that due to the rest mass of the meson, a minimum of about 100 mev. The alpha particle has taken about 18 mev, leaving 82 mev unaccounted for. A small amount might be the binding energy of the alpha particle; the balance may have been used as kinetic energy of the recoiling particle or nucleus, or to excite the residual nucleus, or both. For any substantial fraction of this 82 mev to be used in recoil, the recoiling particle or particles must have been very light, say one, or at most two, protons or neutrons with directions approximately opposite to that of the alpha. More light particles might have been involved if their directions were such that the momenta of all but one or two balanced each other and did not contribute to the momentum balance with the alpha particle. But there are no nuclei common to both emulsions with less than four protons and an alpha particle as possible constituents, and if more than two protons were involved the energies of one or more would probably have been low enough that their tracks would have been detected, since tracks of protons with energies as high as 45 mev have been seen.

The alpha may then have been ejected from one of the heavy nuclei, the residual nucleus being too heavy to have recoiled sufficiently to show a track. The recoil energy of such a nucleus is rather small; the energy left after supplying the binding energy and the kinetic energy of the alpha may have been used in ejecting one or more neutrons, a high speed proton, even a meson of lower mass than the incoming one.

2. Meson-Proton Event.

Two disintegrations were found in which a meson at the end of its range ejected a proton from the nucleus.

In the event* illustrated in Fig. 8, the meson path was 97 microns long and went down steeply into the emulsion as shown in the profile beside the track.

The meson was identified from the low grain count, and from the appearance of the track which showed some scattering. The grain count in comparison with the average of proton tracks in this emulsion, is given in Table IV.

TABLE IV

Residual range (microns)	0	25	50	75	97
Meson grain count	0	26	45	64	79
Proton grain count (av.)	0	39	70	101	128

The proton track was 223 microns long and was completely in the emulsion. It has the appearance of a proton track and this identification is borne out by the grain count, as given below in Table V.

TABLE V

Residual range (microns)	0	25	50	75	100	125
Proton grain count	0	46	89	117	150	
Proton grain count (av.)	0	39	70	101	129	156

The proton track corresponds to an energy of 5.9 mev.

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*Plate C2B159, A3pcs.; p.4.

The second meson-proton event* was due to a meson which entered the emulsion from the air and slanted down fairly steeply into the emulsion for a total length of 59 microns.

The meson track was too short and steep for accurate grain counting, but had the appearance both in grain density and scattering of a meson track. The last 50 microns of the horizontal projection of the track, when corrected for dip in the emulsion and for shrinkage of the emulsion, gave a track length of 75 microns for which the grain count was 84, a figure considerably below the proton grain counts mentioned above, and corresponding roughly with previously given meson grain counts.

The proton track was identified by appearance and grain counts as given in Table VI below:

TABLE VI

Residual range (microns)	0	25	50	75	100
Proton grain count	0	45	91	125	159
Proton grain count (av.)	0	39	70	101	132

This track reached the glass, and while it appeared from the density to be at or nearly at the end of its range, this could not be stated with certainty. The length to the glass was 114 microns to an energy of 3.9 mev.

In both cases the grain density of the proton track was slightly higher than the average, but was lighter than that

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*Plate C2L109, A2pcs.; p.2.

of an alpha particle. This may be taken to indicate that the protons had mass two or three, i.e., were deuterons or tritons. The energy given in the first case for a proton, 5.9 mev, would be 11.8 mev for a deuteron or 17.7 mev for a triton. In the second case, for a deuteron, the energy would be 7.8 mev and for a triton, 11.7 mev.

For the first event, an argument similar to that made in the previous section can be made to show that the proton was probably ejected from a rather heavy nucleus.

A small recoil of about 2 or 3 grains is visible in the second case, where the meson comes to rest. This seems too small and light to be due to a recoil nucleus. It may be an accidental occurrence of background grains or it might be due to beta activity of a nucleus left radioactive by ejection of a proton.

3. Meson and Proton Ejected.

A number of cases were found in which a proton and a meson appeared to have been ejected from a nucleus at the same time. Four of these cases were found entirely in the emulsion and the data for these will be given below.

The first event* is illustrated in Fig. 9. Both proton and meson left the nucleus in the same general direction. The proton track was almost horizontal in the emulsion while the meson track was moving downward into the emulsion. Identification was from appearance, scattering and grain count.

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*Plate C2B157, A2pcs.; p.13.

The proton and meson tracks had their characteristic appearance, the meson track showed considerable scattering and the grain counts, corrected for slope in the emulsion, are given below in Table VII, in comparison with the average count from four proton tracks in the same emulsion.

TABLE VII

Residual range (microns)	0	25	50	75	100	125
Meson grain count	0	29	56	86	110	132
Proton grain count	0	37	78	118	153	182
Proton grain count (av.)	0	33	73	104	136	164

The meson track length was 162 microns while the proton track length was 133 microns which corresponds to 4.3 mev.

The meson track in the second case* had a length of 280 microns and showed considerable scattering. The proton track, corrected for dip in the emulsion, had a length of 87 microns, corresponding to an energy of 3.3 mev. The grain counts were as follows:

TABLE VIII

Residual range (microns)	0	25	50	75	100	125
Meson grain count	0	39	66	91	113	137
Proton grain count	0	39	75	108		
Proton grain count (av.)	0	38	73	104	136	164

In the third such event** the energies involved were

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* Plate C2B157, A2pcs.; p.3.

**Plate C2B157, A2pcs.; p.15.

somewhat greater, the proton track being 285 microns long, while the meson track was about 750 microns long. The grain counts are given in Table IX, below.

TABLE IX

Residual range (microns)	0	25	50	75	100	125
Meson grain count	0	32	62	89	112	138
Proton grain count	0	42	78	113	146	179
Proton grain count (av.)	0	38	73	104	136	164

This particular meson track showed little scattering, but from its grain count and particularly from its appearance in the emulsion it was identified as a meson track.

The fourth of these events* is shown in Fig. 10 and was similar in appearance to the second, but smaller. In this case the meson track was very light and showed considerable scattering. This proton track was short, only 47 microns long when corrected for slant in the emulsion. This represented an energy of 2.25 meg. The meson track was 280 microns long. The grain counts were:

TABLE X

Residual range (microns)	0	25	50	75	100	125
Meson grain count	0	30	48	70	85	105
Proton grain count	0	34				
Proton grain count (av.)	0	38	73	104	136	164

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*Plate C2B157, A2pcs.; p.17.

4. Primary and Secondary Meson (π - μ process)

One example was found of the track of a secondary meson originating at the end of the track of another, or primary, meson. A mosaic of photomicrographs of the tracks is shown in Fig. 11. This type of event was first described by Lattes, Occhialini, Muirhead and Powell (L6) and they have reported a number of other cases subsequently (L7).

This particular event has been described in a letter to the editor of Physical Review by the author and Eric Pickup (M3), not yet published, but since it is a rare and important event and is the first reported outside of Powell's group at Bristol it will be described here.

The primary meson entered through the surface and passed downward through the emulsion, ending 18 microns above the glass. The secondary meson travelled upward through the emulsion and was scattered downwards about 50 microns from the end of its range.

The ranges of the primary and secondary meson as measured in horizontal projection were 176 and 627 microns respectively. A profile showing the vertical path of the mesons through the emulsion is given in Fig. 12. The vertical co-ordinates have been corrected for the shrinkage of the emulsion in processing by multiplying by a factor of 2.5. After correction for vertical travel, the primary and secondary ranges became 213 and 655 microns respectively. The accuracy of the range measurement is believed to be $\pm$ 0.5%. The corrected range of the secondary is somewhat longer than the average range, 614 ± 8 microns, given by Lattes, Occhialini and Powell (L7).

Identification of the tracks as due to mesons was made by their scattering, which was greater than that of protons of comparable range, and by the grain counts as compared with that of protons. The total number of grains in the primary or π -meson track was 141 and the grain counts for the last 50, 100 and 150 microns were 46, 77 and 106. For the secondary or μ -meson the corresponding figures were 263 grains and 43, 80 and 112 grains (average grain size in the emulsion = 0.4 micron). The distances were corrected for slant in the emulsion as deduced from the profile given above, and are thus the distances along the path of the mesons when the event took place.

The differences in the grain counts of the π and μ mesons were not great enough to give any positive indication of mass difference. In view of the shortness of the primary track and the statistical uncertainty involved because of the small number of grains, all that can be said is that the possibility of a difference in mass cannot be excluded.

5. Small Star produced by Meson from Star.

Although a number of cases were found of mesons being produced in nuclear disintegration along with protons and alpha particles (see below) only one case was found in which a meson produced in a disintegration, itself produced a disintegration. This one case is shown in Fig. 13. Track number five of the large disintegration star, numbering clockwise from 12 o'clock, is that of a meson originating in the energetic disintegration and producing a four-particle disintegration. Two of the tracks of the meson-produced disintegration leave the emulsion and all are too short for positive identification, but they might be due to three alpha particles and a proton.

Since the meson produced a disintegration it may be assumed to be negative and if the identification of tracks is correct, they may be due to disintegration of an oxygen nucleus.

This primary star shows two heavy fragments, the longer of which leaves the emulsion. Only one other track, a proton track, is completely in the emulsion, so the identity of the primary nucleus cannot be determined.

6. <u>Secondary Event Associated with Track from Star</u>.

In one case* a track from a star was observed to stop and to give rise to another track at an acute angle to it. This event is illustrated in track 2, Fig. 14.

The first track is 78 microns long, is entirely in the emulsion and ends about 7 microns lower than the vertex and about 17 microns above the glass. The other track appears to originate from the end of the first one, is 170 microns long, goes down slowly, ending at the glass. Neither track shows the scattering usually associated with a meson.

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*Plate C2B159, A7pcs.; p.l.

The grain counts are given in Table XI below, the count being away from the end of the short track in each case. For comparison the count on the secondary or μ-meson of the section four is given.

TABLE XI

Residual Range (microns)	0	25	50	75	100	125	150	170
Short track	0	27	49	65				
Longer track	0	21	34	52	71	90	112	126
μ-meson	0	6	10	15	21	24	31	37
Proton (av.)	0	39	70	101	132	156	183	

The grain count of the longer track is much heavier than that of a μ-meson at the beginning of its path but is considerably lighter than that of any but a very energetic proton. The grain count of the shorter track is likewise lower than that of any proton except an energetic one near the end of its range.

The absence of any recoil and the decrease in grain density after change of direction eliminates the possibility of the track being due to deflection of an energetic proton. This same star shows two other deflected tracks, one, number three, shows a recoil track and an increase in grain density immediately after the deflection. The other, number five, an alpha track, showed both a recoil (not visible in the photograph) and a considerable increase in grain density after deflection.

It is hard to give an interpretation of this track or pair of tracks since they do not correspond very well to those of either protons or mesons. It was thought at first that this might be a case of a primary and secondary meson, but grain counts and the appearance of the tracks do not confirm this.

One explanation which might be advanced somewhat tentatively is that the short primary track is due to a deuteron which entered a heavy nucleus causing the ejection of a proton of less energy but higher velocity.

7. Mesons from Stars.

Although not all of the larger stars have been carefully analysed as yet, seven cases of mesons emitted along with protons and alpha particles in nuclear disintegration have been found in those stars which have been examined. Counting the meson which produced a disintegration, (Section 4, above) eight mesons emitted from stars have been found in an incomplete study of 942 stars of three prongs or more.

The eight mesons which produce no disintegrations may be positive mesons and are presumably almost all light ones, since none of them gives rise to a secondary or -meson, as do a considerable fraction of the positive heavy mesons produced by Gardener and Lattes (G1).

8. Miscellaneous Meson Events.

A number of events involving mesons are illustrated in

Figures 15, 16 and 17. In Fig. 15* a meson produced a three particle disintegration. Only one of these tracks ended in the emulsion and it was identified as an alpha particle. The other two passed out through the glass and air and could not be identified.

In Fig. 16**, a meson track can be followed about 400 microns from the glass through the emulsion; it suffers an abrupt bend, and after another 39 microns a disintegration occurs with a heavy short track and a longer more energetic one, which goes downward and passes into the glass before it reaches the end of its range. The grain count for the meson track is given in Table XII for comparison with proton grain count in the same emulsion.

TABLE XII

Residual range (microns)	0	25	50	75	100	125	150
Meson grain count	0	31	62	90	112	136	157
Proton grain count (av.)	0	37	72	103	132	160	183

The short thick track ends in the emulsion and seems to be due to a nuclear fragment heavier than an alpha particle, while the third track, which goes out of the emulsion into the air, may be due to a proton.

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* Plate C2D5, A4pcs.; p.1.

**Plate C2B159, A2pcs.; p.5.

The third event* is a four particle disintegration in which one of the particles has produced a secondary disintegration in which a nuclear fragment and an alpha particle were released. This disintegration is shown in Fig. 17. The track of the particle causing the disintegration is too short for positive identification. The two long tracks end in the emulsion and both are proton tracks.

B. Phenomena not Involving Mesons.

1. Alpha-Proton Disintegration.

Disintegrations were observed which consisted of two tracks, one an alpha particle and the other a proton. Fourteen of these were found which were entirely in the emulsion. Three of these tracks were photographed and these photographs are included here as Figs. 18, 19 and 20.

In Fig. 18 the proton and alpha track can be clearly distinguished** The alpha track is about 130 microns long and the proton track is about 535 microns long, representing respectively energies of 15.8 mev and 9.7 mev.

The tracks*** illustrated in Fig. 19 were much smaller, the length of the proton track being 116 microns and that of the alpha, 12 microns. The energies here were 3.4 mev for the alpha and 3.9 mev for the proton.

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* Plate C2L109, A4pcs.; p.15.

** Plate C2L100, A2pcs.; p.1.

***Plate C2L98, A2pcs.; p.7.

The third pair of tracks*, Fig. 20, represented an energetic disintegration; the alpha track, 111 microns long, corresponded to 14.0 mev, and the proton track, 460 microns long, to 8.9 mev.

The first pairs of tracks of this kind were found in a lithium-loaded emulsion and it was assumed that this was the neutron-induced reaction,

$$ {}_{3}Li^{6} + {}_{0}n^{1} \longrightarrow {}_{2}He^{4} + {}_{1}H^{3} $$

Subsequently events of this kind were seen in emulsions which did not contain lithium and some of these events were entirely in the emulsion so that there was no ambiguity about their interpretation. From this it would appear that in at least some cases, the proton and alpha particle were ejected from a nucleus other than that of lithium.

However, although some such events were found in other emulsions, the number found in lithium loaded emulsions was disproportionately high, so that it would appear that the reaction given above does occur, and that the lithium-loaded emulsions may contain pairs of tracks from the disintegration of lithium by neutrons as well as pairs from heavier nuclei.

The ejection of alpha and proton from nuclei other than lithium is also indicated by the presence in a few cases of short recoil tracks, some fairly heavy and others quite light. The heavier recoils may be due to the recoil of a light residue, though this seems unlikely since some of these disintegrations are quite energetic and any light recoil would

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*Plate C2L97, A2pcs.; p.l.

leave a longer track than those seen. The lighter and heavier 'recoil' tracks may not be recoils at all, but may be grains made developable by beta rays from a residual nucleus left radioactive by emission of the alpha and proton.

Low energy disintegrations of lithium into protons and alpha particles were not observed and this indicates that very few slow neutrons were present in the cosmic rays at high altitudes.

2. <u>"Hammer" Tracks</u>.

An event believed to be due to the interaction of a fast neutron with a boron nucleus is shown in Fig. 21. This was found in a boron-loaded emulsion*and consisted of an alpha track 132 microns long, and a Li^8 track 39 microns long. At the end of the Li^8 track, two alpha tracks, each 7 microns long and in opposite directions, resulted from the disintegration of Be^{8*}. This reaction is:

$$ {}_5B^{11} + {}_0n^1 \longrightarrow {}_3Li^{8*} + {}_2He^4 + Q_1 $$
$$ {}_3Li^{8*} \longrightarrow {}_4Be^{8*} + e^- $$
$$ Be^{8*} \longrightarrow {}_2He^4 + {}_2He^4 + Q_2 $$

This track is of particular interest since it was first produced in this laboratory a short time ago by exposing boron-loaded plates to fast neutrons from the bombardment of lithium with 600 kv deuterons. Two of the tracks obtained

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*Plate C2B158, CSS, p.3.

are pictured in Fig. 22. The upper one, the first obtained, has been reported by E. Pickup in a letter to the editor of the Physical Review (P10).

The only other "hammer" track found is shown in Fig. 23. A heavy nuclear fragment, Li^{8*}, was ejected in a disintegration, and decayed into Be^8, which being excited and unstable, disintegrated into two alpha particles.

The other three tracks of this disintegration were rather tentatively identified as an alpha particle and two protons, so that the reaction might be due to disintegration of nitrogen by a fast neutron.

This "hammer" track is the only one observed among the tracks of the 1100 stars found so far. This is a lower proportion than may be inferred from the 28 "hammer" tracks mentioned by Franzinetti and Payne (F5) of the Bristol group, and the approximately 10,000 stars mentioned by Occhialini and Powell (O4) as having been observed by this group.

3. Three Particle Events.

About 270 three-particle events were found in the emulsion and analysed. Of these 28 were entirely in the emulsion. A study of these, checked against others which were not entirely in the emulsion, indicated that there were two principal types, those which consisted of two alpha tracks and a proton and those which consisted of two protons and an alpha particle. A single event was found in which the three tracks appeared to be those of protons.

The disintegrations having two alpha particles and a proton were found in greater numbers in boron-loaded plates, but were also found in unloaded and in lithium-loaded plates. These disintegrations may be in part due to the fast neutron disintegration,

$$_5B^{10} + {_0n^1} \longrightarrow {_2He^4} + {_2He^4} + {_1H^3}$$

but must also be due to another process in which these particles and possibly neutrons and very high-energy charged particles which leave no visible tracks are emitted. An example* of this type is shown in Fig. 24.

The other type of disintegration, two protons and an alpha particle, could not have represented the complete disintegration of a nucleus in the emulsion since no nucleus with this total charge was present. It might be explained as fragments knocked out of a heavy nucleus by an energetic neutron or other particle.

The 'star' consisting of three proton tracks was found in a lithium-loaded plate and may have been due to the disintegration of a lithium nucleus. This is not necessarily the origin, however, as it may have been split off from a heavier nucleus.

4. Four Particle Events.

As the number of prongs increases the probability of getting events wholly in the emulsion decreases very rapidly.

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*Plate C2B160, A3pcs.; p.10.

Of the 268 four-prong disintegrations found, only nine were entirely in the emulsion. With the increasing number of tracks, those events which have only one long track, the rest being short, are found entirely in the emulsion much more frequently than those which have two or more long tracks. The chance of finding completely in the emulsion any four particle event, where all particles have high energies, is very small.

The nine events found must therefore be considered as rather arbitrarily selected from the various four particle disintegrations by the criterion that all tracks end in the emulsion.

At least two types of disintegrations appear to occur and this is confirmed by study of other events not completely in the emulsion; one type of disintegration gives rise to two alpha particles and two protons, the other, apparently more frequent, gives rise to three alphas and a proton. In addition to these, other types of disintegration may occur, but have not been recognized.

These tracks may be due to the disintegration of light nuclei or may be ejected from heavier ones or both processes may be taking place. The evidence is insufficient to decide this question. If the tracks are from light nuclei, the three alphas and a proton might have come from the disintegration of nitrogen and the two alphas and two protons may be due to the disruption of carbon.

5. Five Particle Event.

A single disintegration with five tracks all in the emulsion was found. This type of event may be a very unusual one in view of the considerations mentioned above. It is the only one of the 149 five-particle 'stars' found which was entirely in the emulsion.

The five tracks were identified as three alphas and two protons. This identification should not be given too much weight as the three tracks identified as due to alpha particles were less than 25 microns long. (#1, 8 microns; #2, 11 microns, #5, 22 microns). The other two tracks due to protons were 84 microns and 1038 microns long. One of these was heavy enough to be due to a proton of mass two or three, i.e., a deuteron or triton.

If this were due to the disintegration of a single nucleus by a neutron, the charge would indicate that the nucleus was oxygen. The total energy of the tracks, assuming three alphas, a proton and a triton, is approximately 35 mev. The energy required to make up the mass defect of the oxygen breaking into these parts is 42.5 mev so that nearly 80 mev would be required of the particle causing the disintegration.

6. Large 'Stars'.

From the data given in Appendix V on the frequency of 'stars' of various numbers of emitted particles, it can be seen that 'stars' of more than 15 tracks are very rare.

Only three cases were found and these had 21, 23 and 26 tracks. A photomicrograph of the largest one* is reproduced in Fig. 25. This is one of the largest, if not the largest, 'star' yet reported and is believed to be the largest photographed.

A minimum estimate of the total energy of the tracks, gives about 194 mev. The actual energy is far greater than this since many of the tracks are in the emulsion only a small part of their total length.

7. Long Proton Tracks.

Two proton tracks, longer than any yet reported, were found in the course of this work. The longest proton track was found in the 26-prong 'star' mentioned above. This track was over 8400 microns long and by extrapolating the (extrapolated) values of Camerini and Lattes (Appendix II) appeared to have an energy greater than 47 mev.

The other long proton track** was over 7000 microns long. This track entered the emulsion from the glass and came to an end in the emulsion. The energy in this case was greater than 42 mev.

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* Plate B2L62, CSA; p.1.

** Plate C2L101, CSS; p.3.

. SUMMARY AND CONCLUSIONS

The phenomena described above, produced in photographic emulsions by cosmic rays, may be grouped into those produced by mesons, those apparently produced by neutrons, and those for which the initiating agent or particle is not yet known.

In the first group, the ejection of an alpha particle or of a proton from a nucleus has been observed to occur, but the nature of the interaction by which the single particle was emitted is not known, though as was argued above, it seems probable that the nucleus affected was a heavy one, i.e., silver, bromine or iodine.

In other cases the meson reacting with the nucleus produced two or three particles and in two of these cases the meson itself was the result of a disintegration.

The decay of a meson into a secondary meson and some other particle (unobserved), as reported earlier by Powell has been confirmed, but the range of the secondary meson is greater than he reports, principally because it is more nearly the true range in the emulsion, rather than the horizontal projection on the top surface.

The disintegration of boron into an alpha particle and an excited Li^8 nucleus which is radioactive and which through emission of an electron becomes Be^8 and breaks up into two alpha particles, is so similar to the disintegration produced by fast neutrons in the laboratory, that it may be ascribed to a very fast neutron. The energy of this neutron cannot be computed for lack of a range-energy relation for lithium in the emulsion, but must be greater than the sum of the threshhold energy for the reaction (6.7 mev), the energy of the two short alpha tracks (4.4 mev) and energy represented by the long alpha track (16 mev), that is, it is greater than 27 mev.

The disintegrations which result in the appearance of an alpha particle and a proton (triton) may, also in part, be ascribed to fast neutrons, since they appear with greater frequency in lithium-loaded emulsions than in others and may be due to the fast neutron disruption of the Li^6 nucleus.

No identification of the disrupted nucleus, or of the disrupting agent, can be made for the ejection of a proton and a meson from a nucleus, for the formation of large and small disintegrations, or for the alpha and proton event in emulsions which do not contain lithium.

Although more information could probably be obtained from additional exposures of the same kind, and from the accumulation of several times as much data, it seems probable that much ambiguity would still remain in the interpretation of the data.

A type of experiment which has more promise than a continuation of the aircraft exposures, is the exposure of plates at a series of altitudes on a mountain or mountains, since the plates are at a fixed and known altitude for the known period of exposure, variations in frequency of occurence of different kinds of events with time and altitude can be accurately found. The time in which fading of a track becomes enough to interfere with its identification, sets a limit on the length of exposure. The maximum yield of events for a given altitude will be secured when the plate can be left at that altitude for the whole exposure time, as is the case in mountain-top exposures. The disadvantage is that mountains of sufficient altitude, say 15,000 feet or more, are not accessible, and the physical difficulties of placing the plates at high altitude and recovering them are very great.

One location was considered where it might be possible to get exposures at 19,000, at 16,000, at 11,000, at 5,000 feet and at sea level, but nothing has been done about it as yet.

Another direction in which further experimentation should be done and probably will be done soon, is in the bombardment of plates with very high energy neutrons, 35 to 50 mev or more, to see if any of the observed disruptions can be reproduced.

This may be tried also with high energy protons and mesons as soon as they can be obtained.

By selective loading of plates, and bombardment with known particles of known energies, some of the puzzling phenomena may be unravelled and information on the nuclear structure deduced.

VII. ILLUSTRATIONS

Figure 1

Range Distribution for Lithium-Slow Neutron Reaction

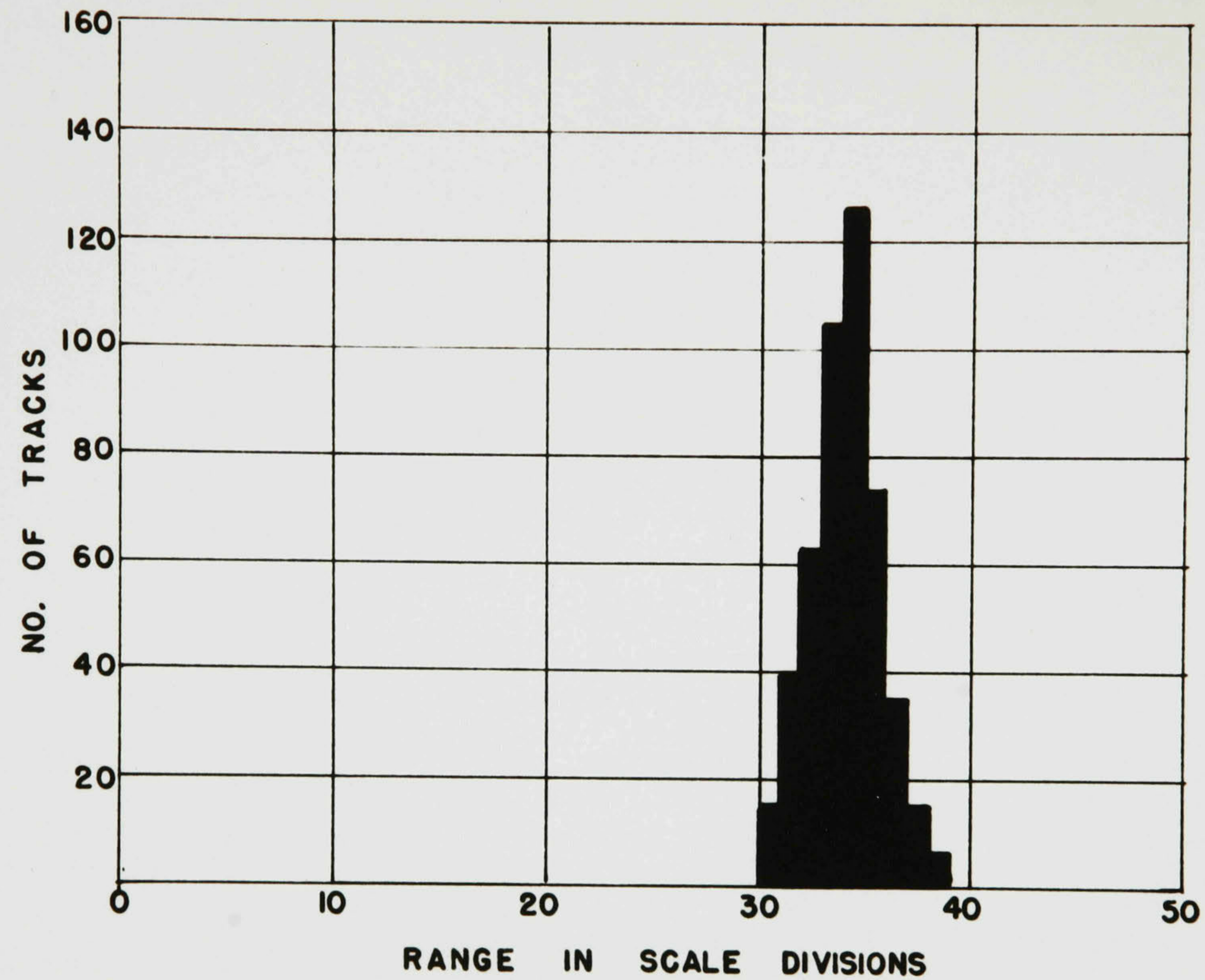

NO. OF TRACKS
160
140
120
100
80
60
40
20
0
10
20
30
40
50
RANGE IN SCALE DIVISIONS

Figure 2

Inhomogeneity in Lithium Loading

of Emulsion.

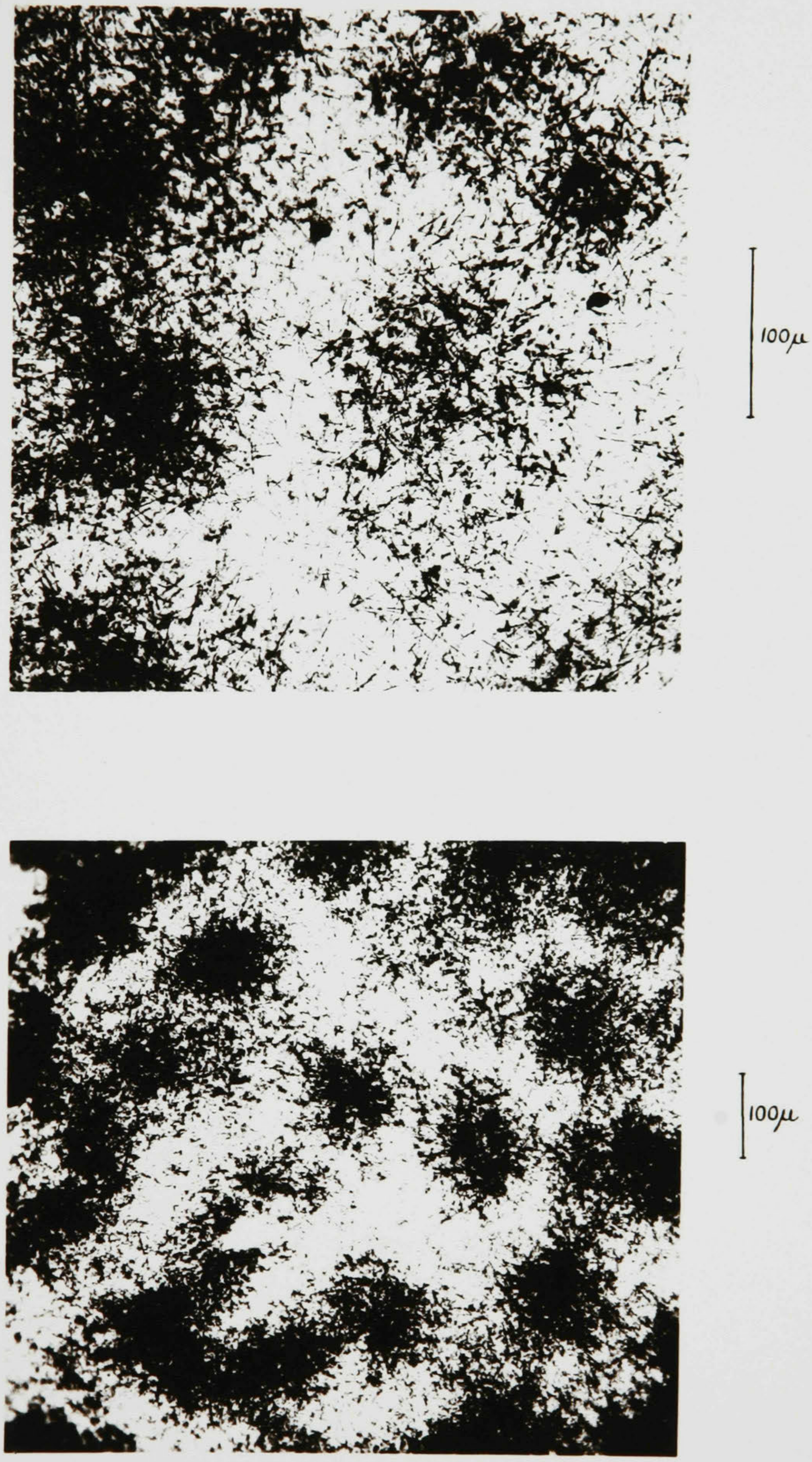


FIGURE 2

Figure 3.

Developing Machine.

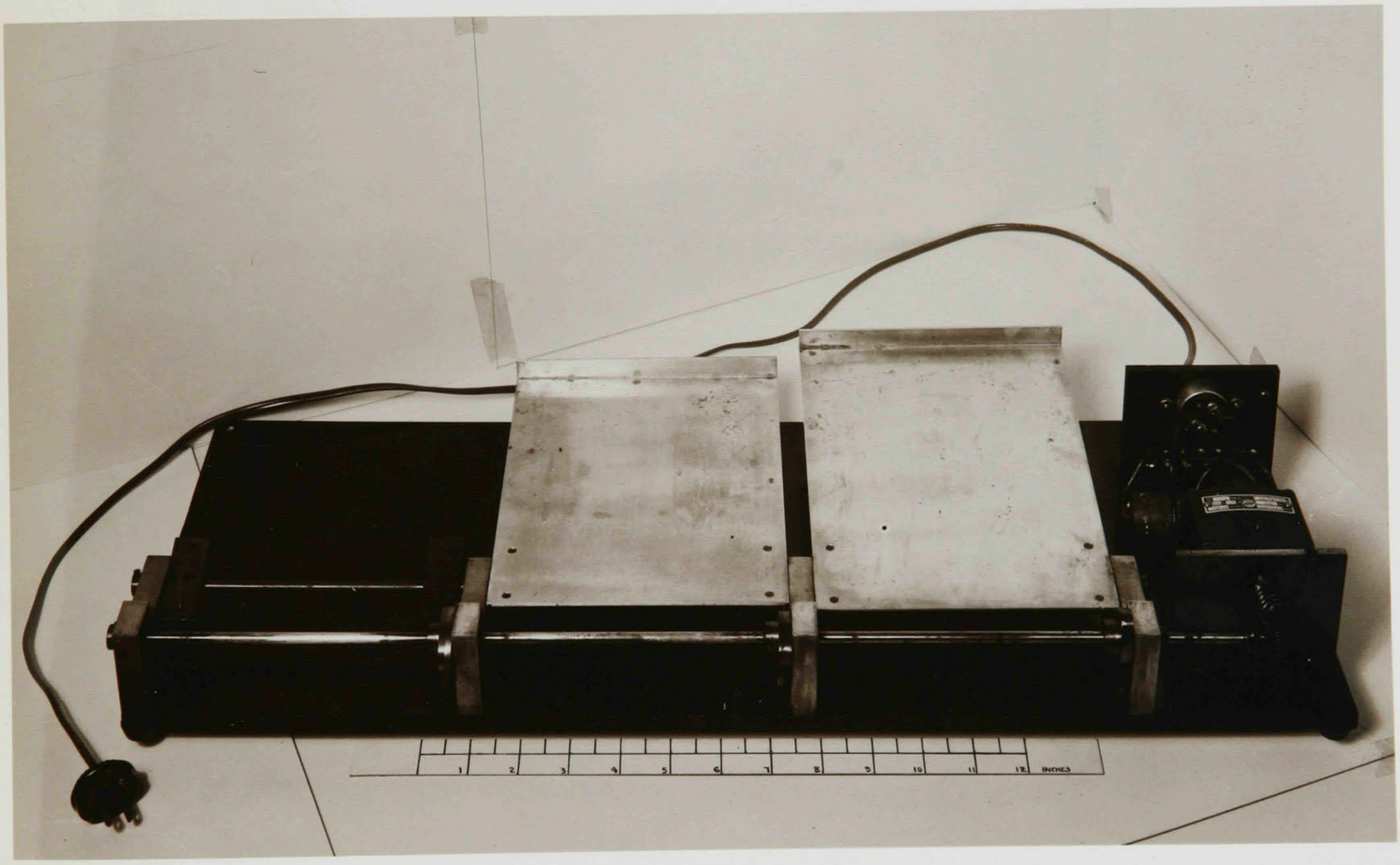

1 2 3 4 5 6 7 8 9 10 11 12 INCHES

Figure 4

Projection Equipment

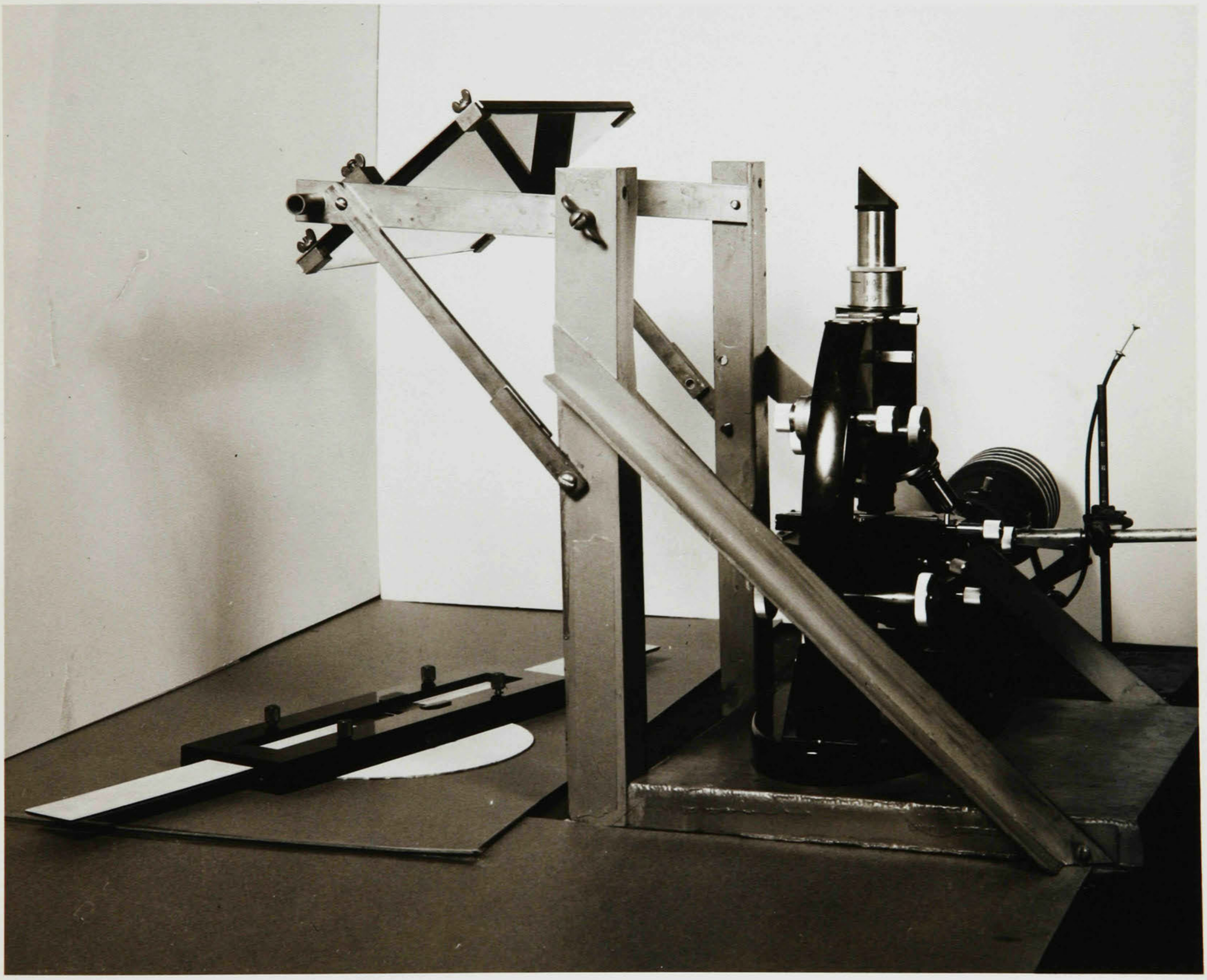


FIGURE 4

FIGURE 5

Plate Carrier

Figure 6

Alpha Particle Ejected by Meson

FIGURE 6

Figure 7

Alpha Particle Ejected by Meson

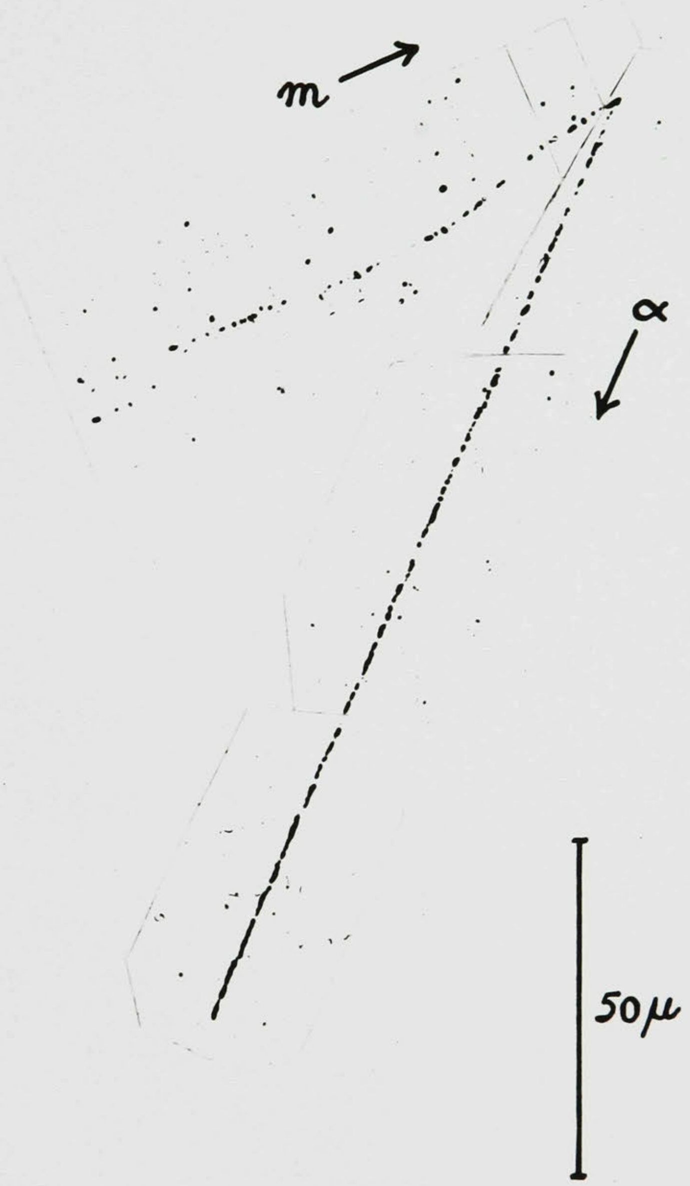


FIGURE 7

Figure 8

Proton Ejected by Meson

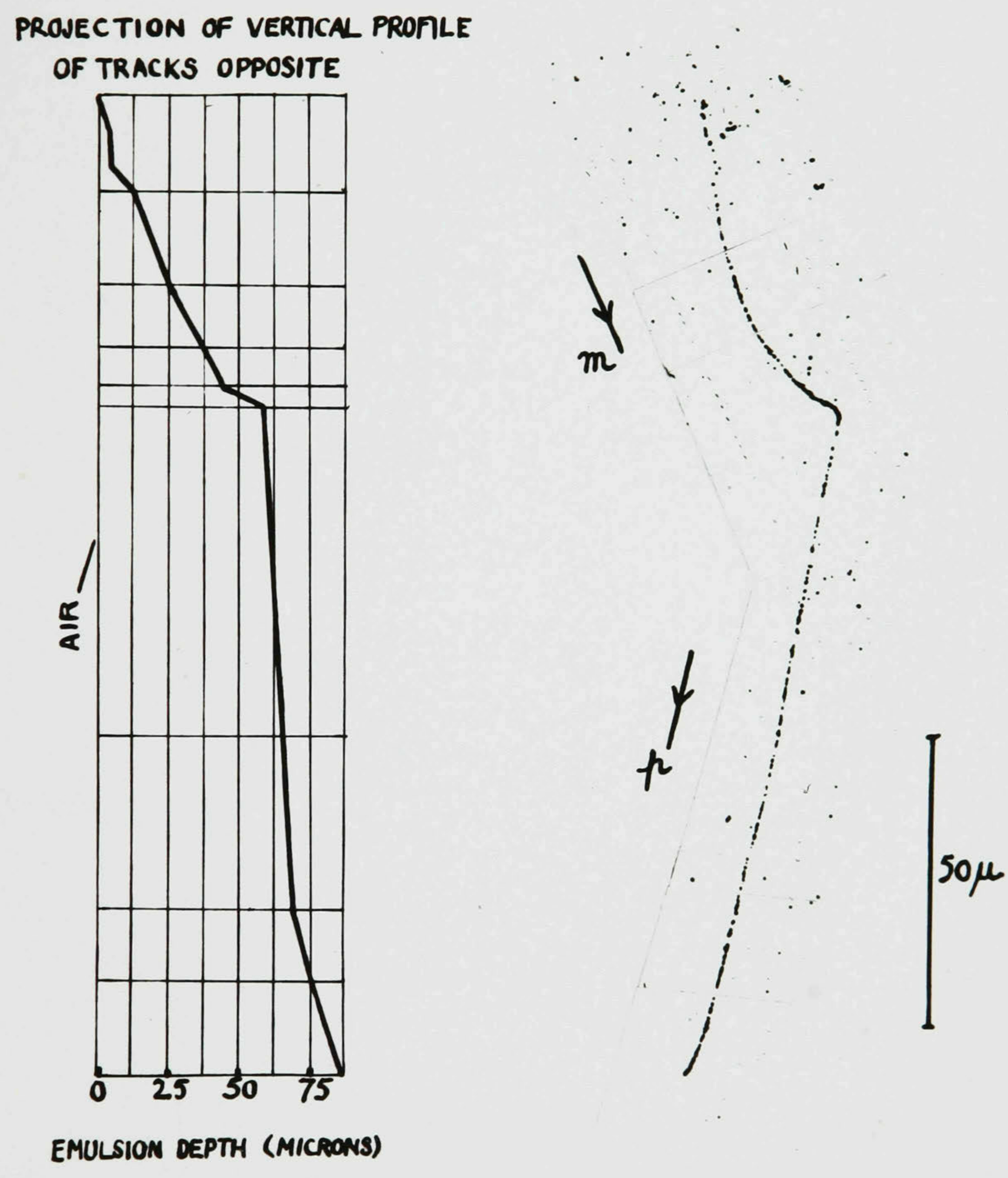

PROJECTION OF VERTICAL PROFILE
OF TRACKS OPPOSITE
AIR
0
25
50
75
EMULSION DEPTH (MICRONS)
m
p
50μ

FIGURE 8

Figure 9

Meson and Proton from Nucleus

FIGURE 9

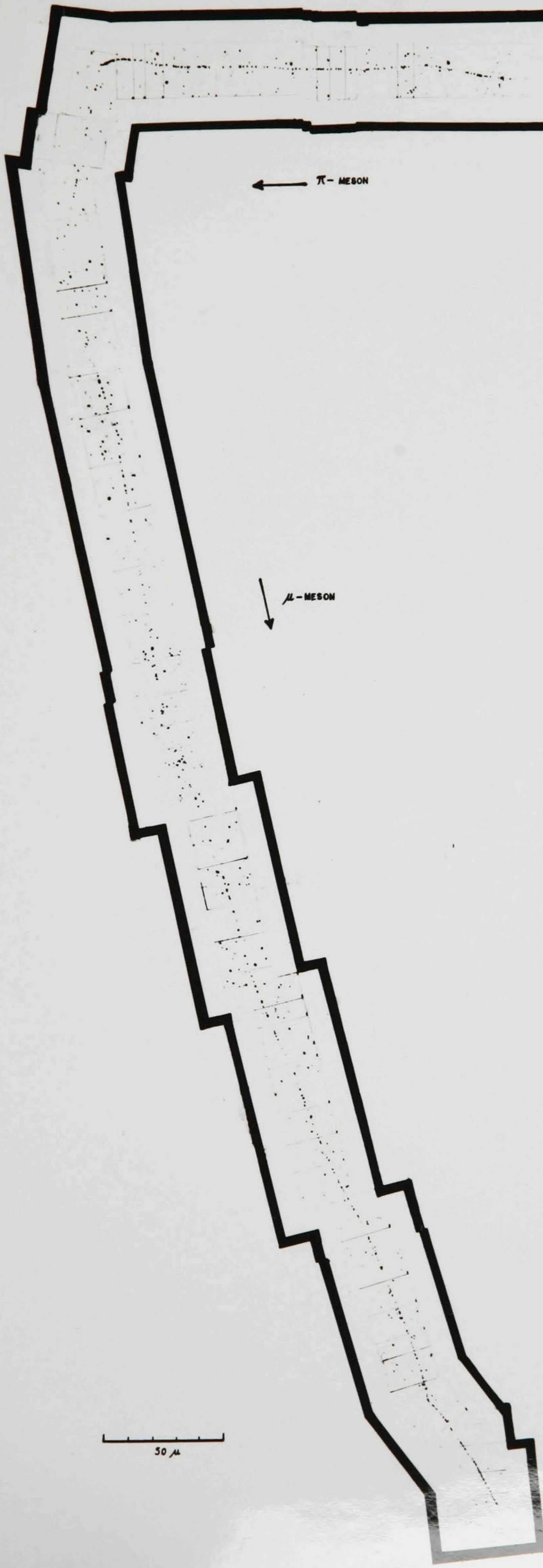
Figure 10

Meson and Proton from Nucleus

50μ
m
p

Figure 11

Primary and Secondary Meson



π- MESON
μ-MESON
50 μ

Figure 12

Profile of Tracks of Mesons

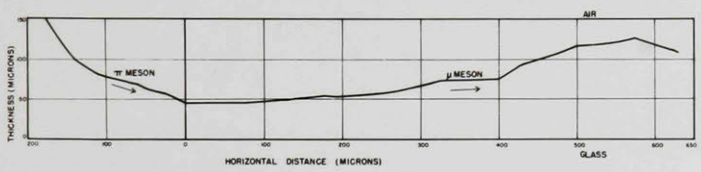


Figure 12

Meson Track Profile

Figure 13

'Star' Produced by Meson from 'Star'

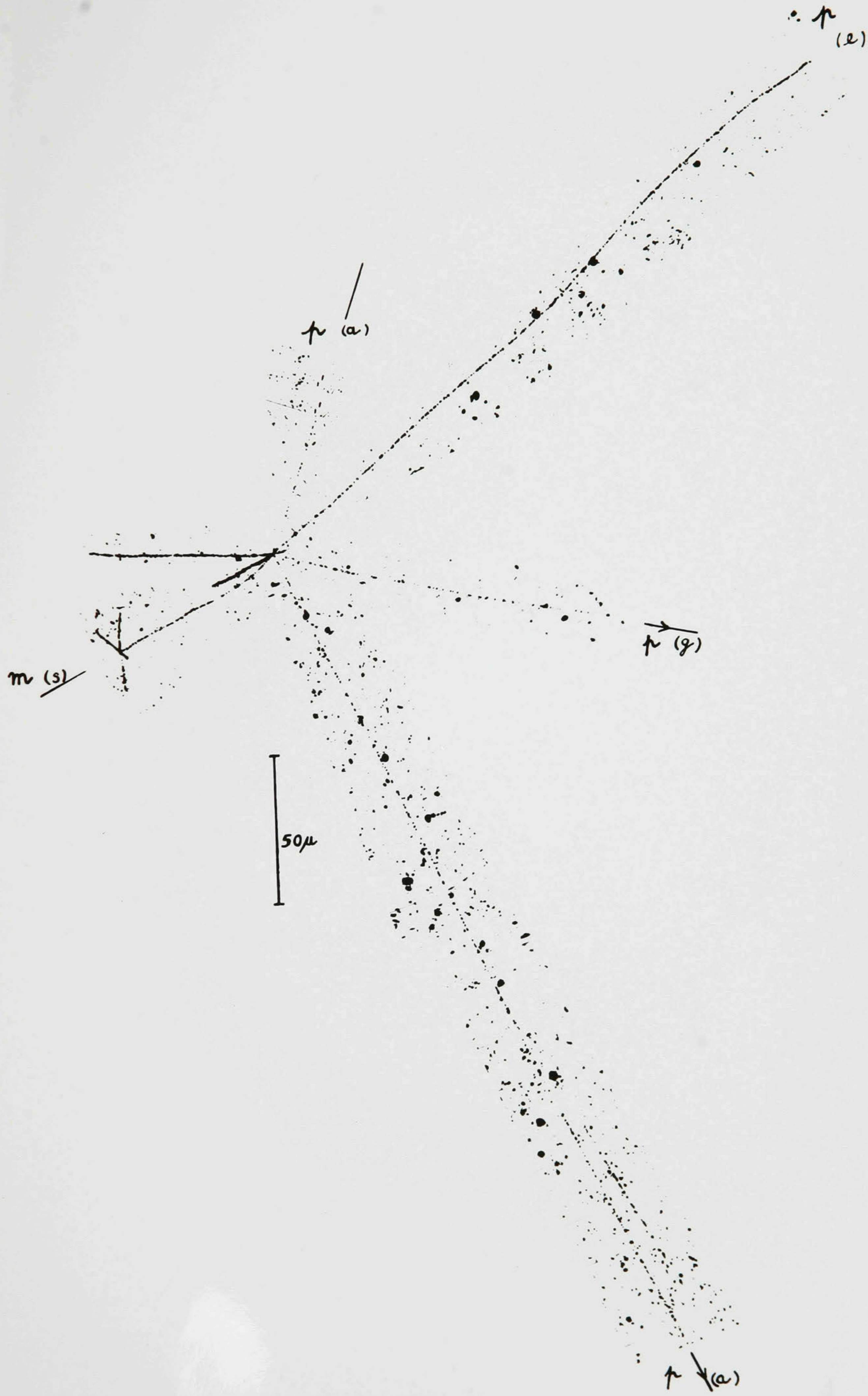
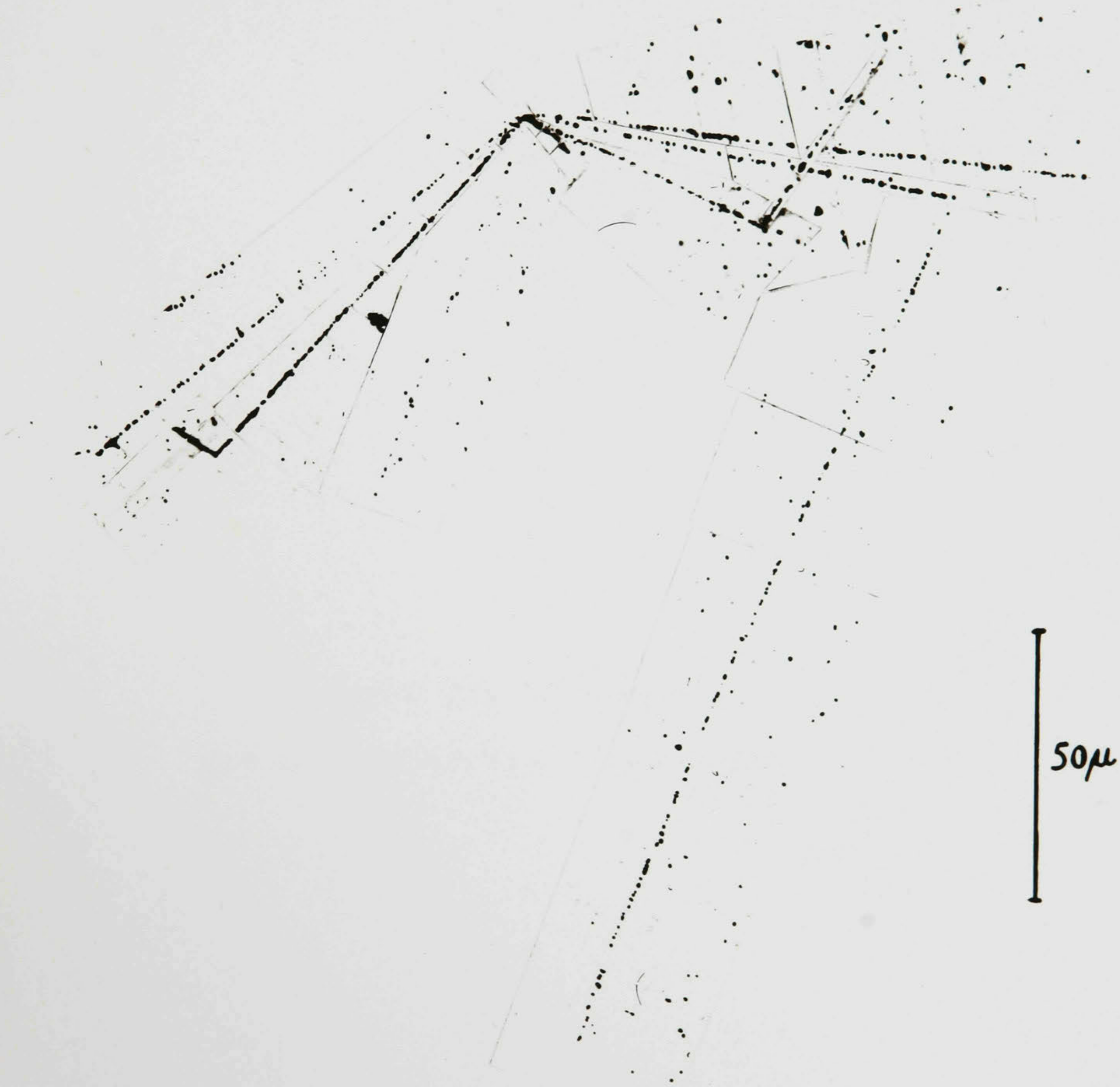

p (e)
p (a)
p (g)
m (s)
50μ
p (a)

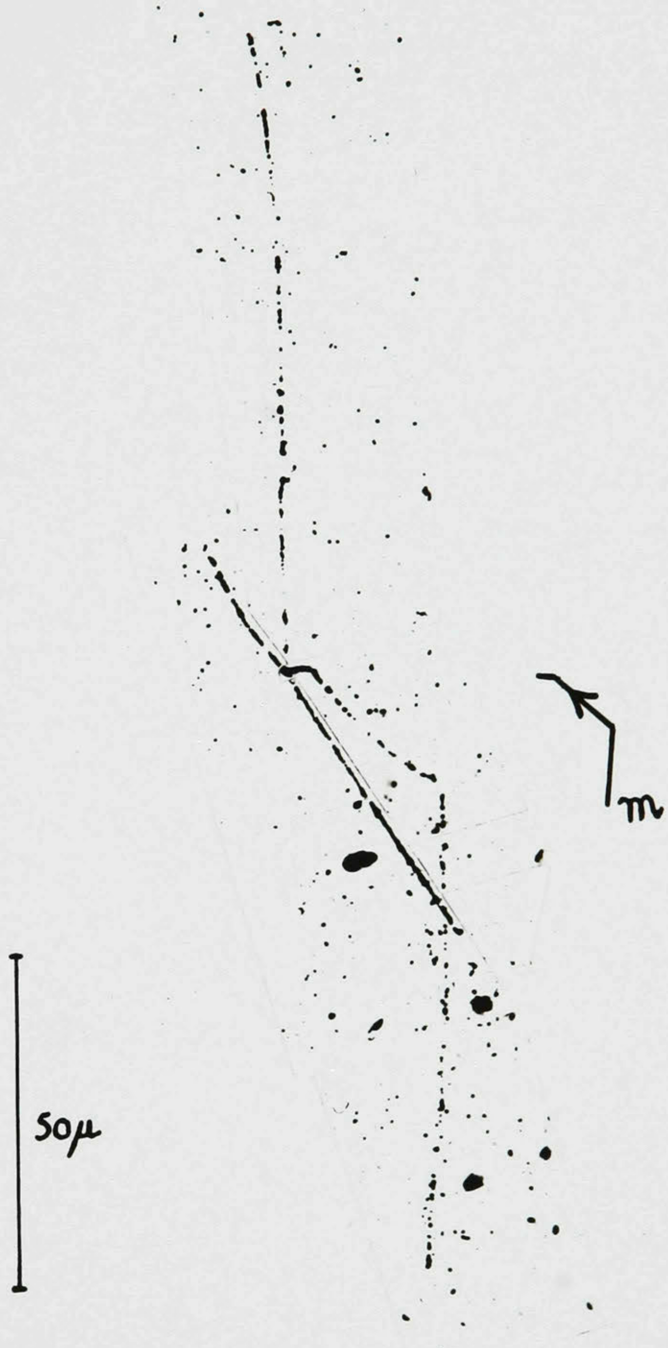
Figure 14

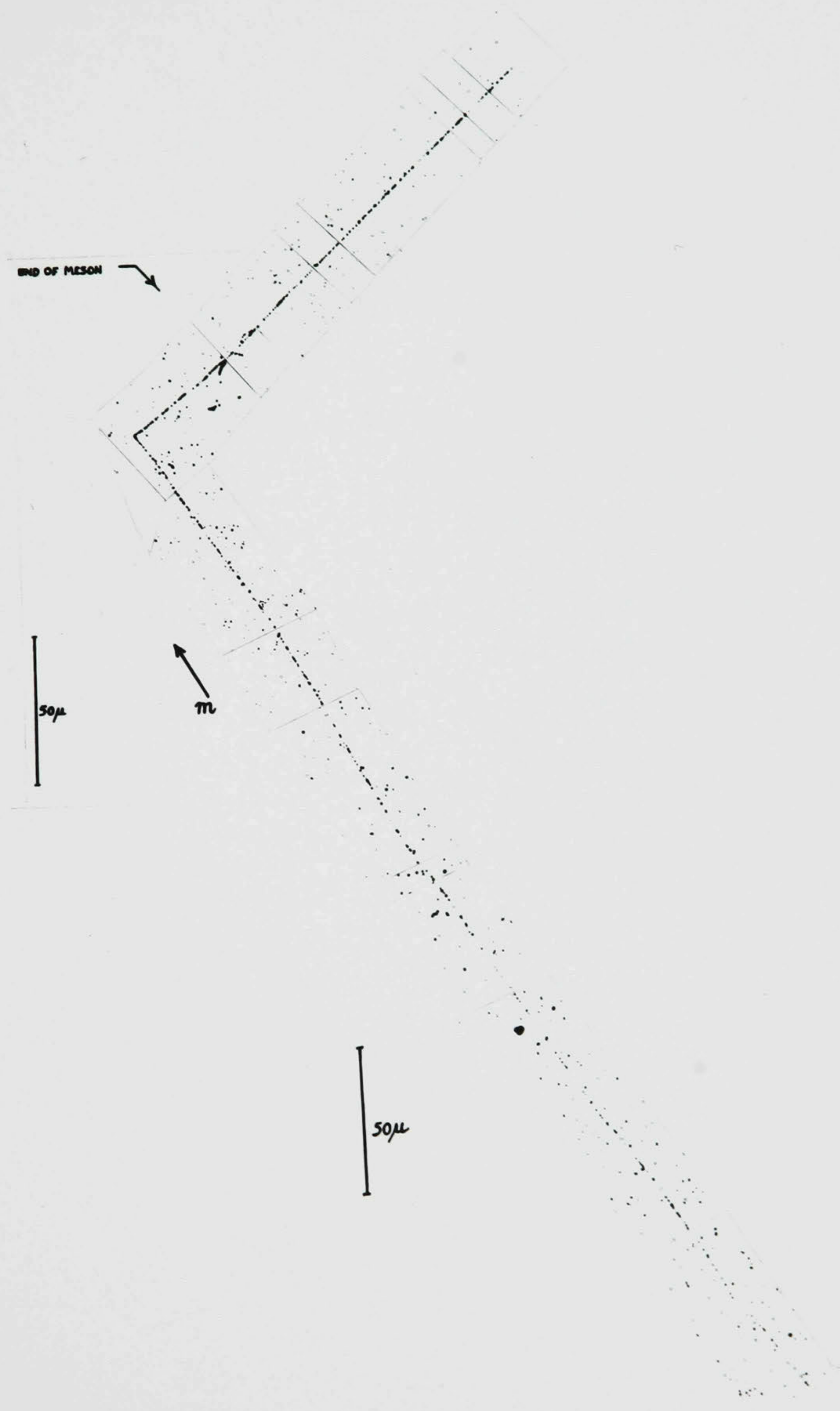
Secondary Event

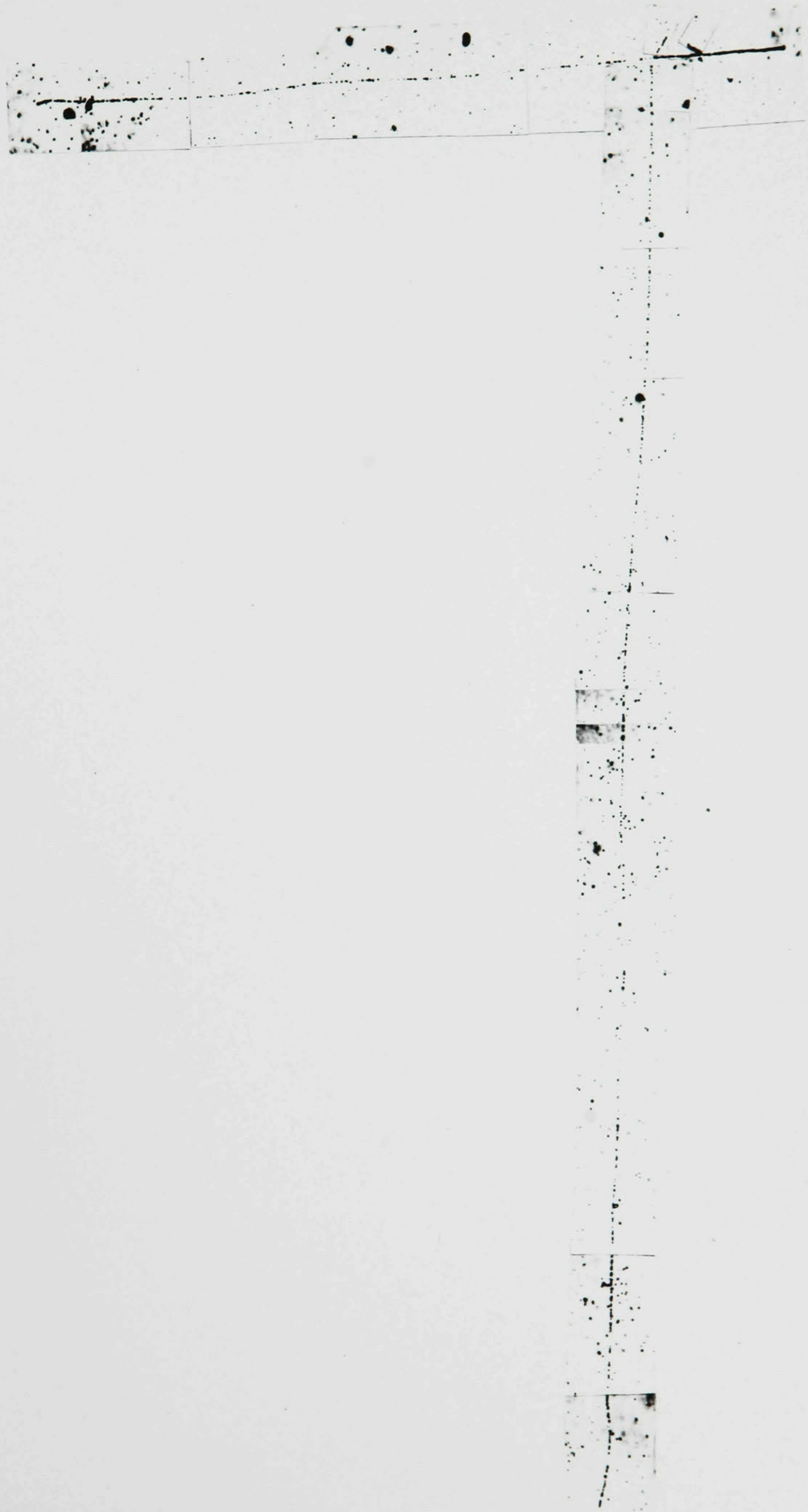

50μ

Figures 15, 16 and 17

Meson-Induced Disintegrations


m
50μ


END OF MESON
50μ
m
50μ



Figures 18, 19 and 20

Alpha Particle and Proton

from Nucleus

50μ

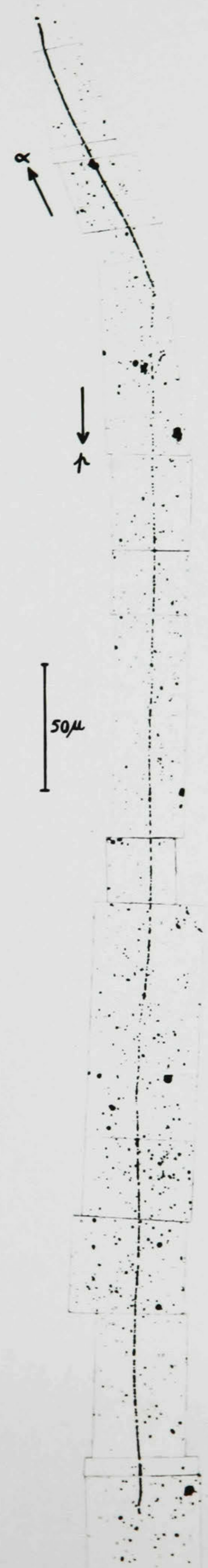

α
p
50μ

Figure 21

"Hammer" Track in Plate

Exposed to Cosmic Rays

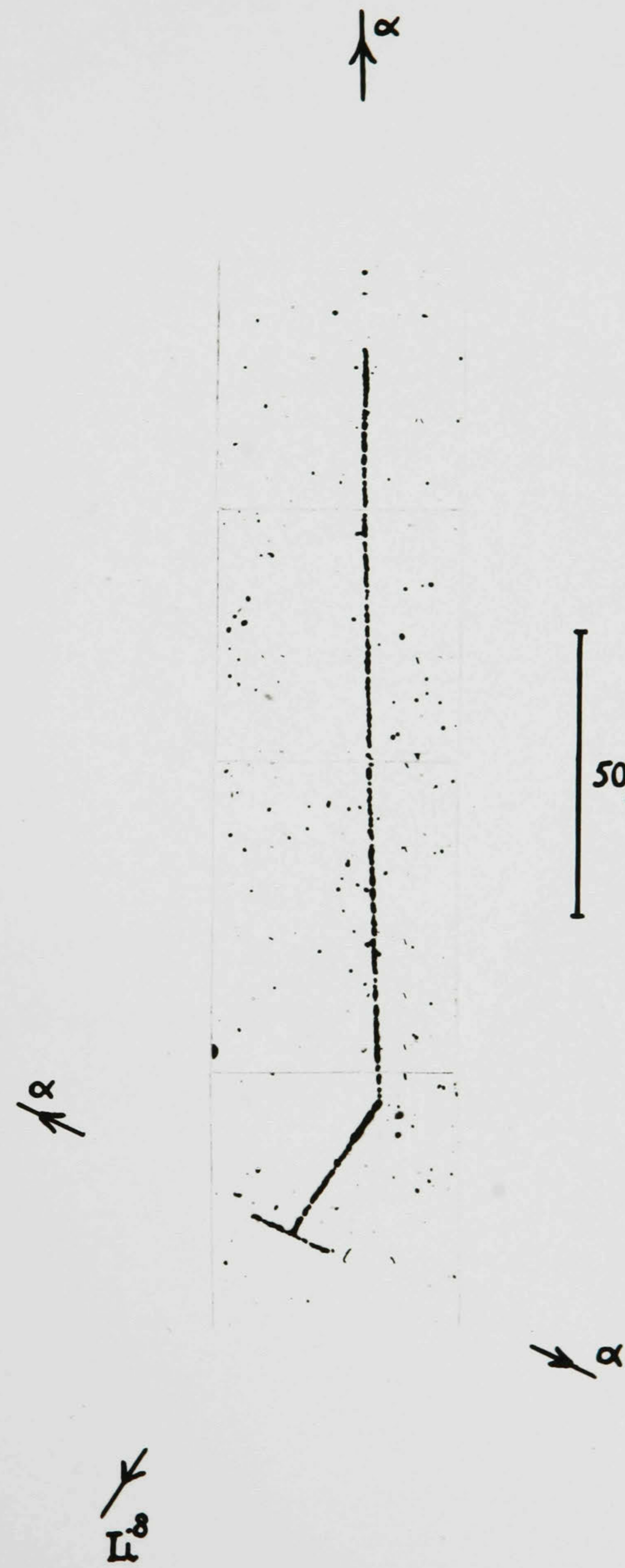

α
50μ
α
α
Li8

Figure 22

"Hammer" Tracks in Plate

Exposed to Fast Neutrons

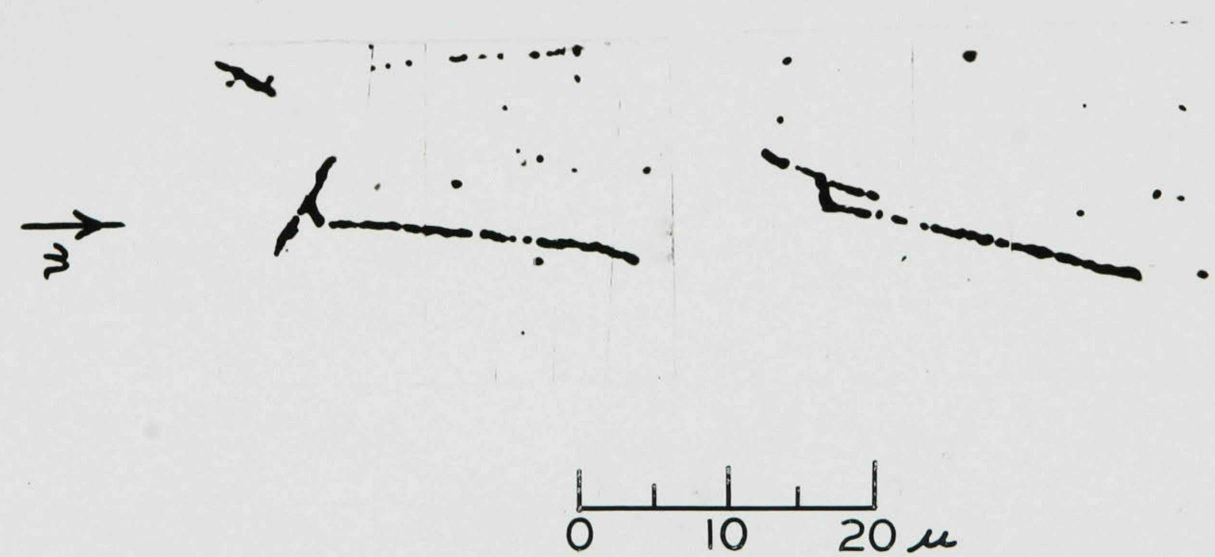

n
0
10
20 μ

Figure 23

"Hammer" Track in Cosmic 'Star'

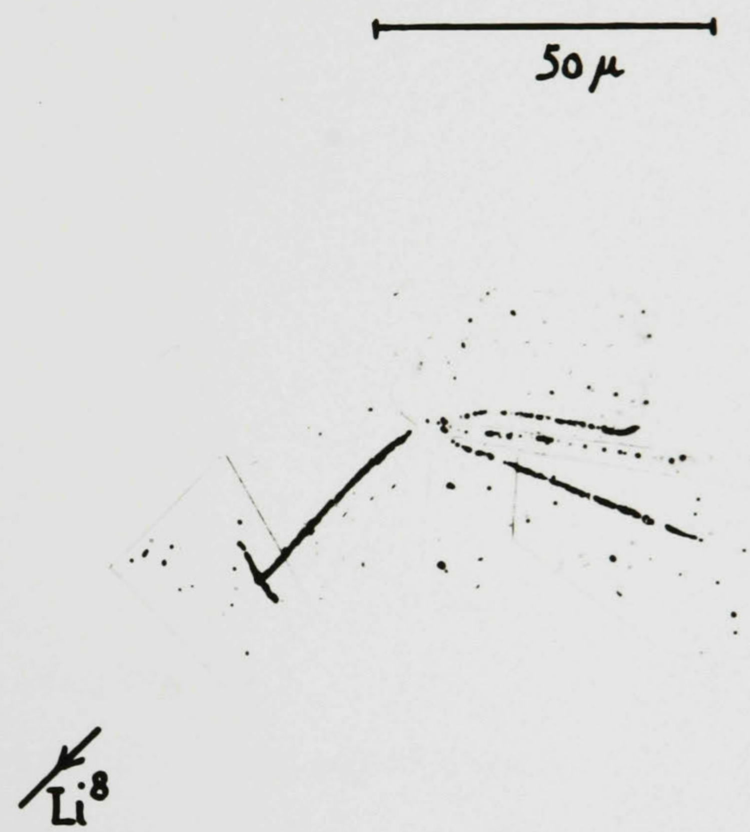

50 μ
Li8

Figure 24

Three Particle Disintegration

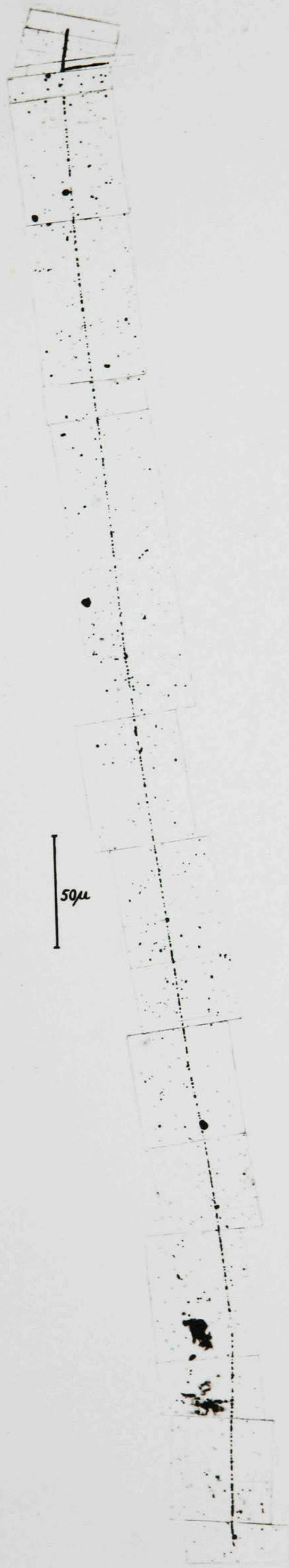

50μ

Figure 25

Twenty-Six Particle Disintegration

100μ
1(a) 2(a)
3(e)
4(e)
5(g)
6(g)
7(g)
8(a)
9
Ex > 47 MeV
if Proton
10(g-)
11(e)
12(a)
13(e)
14(g)
15(g-)
16
17(a)
18(a)
19(e)
20(e)
21(a)
22(g)
23(a)
24(a)
25(a)
26(a)

APPENDICES.

APPENDIX I

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APPENDIX II

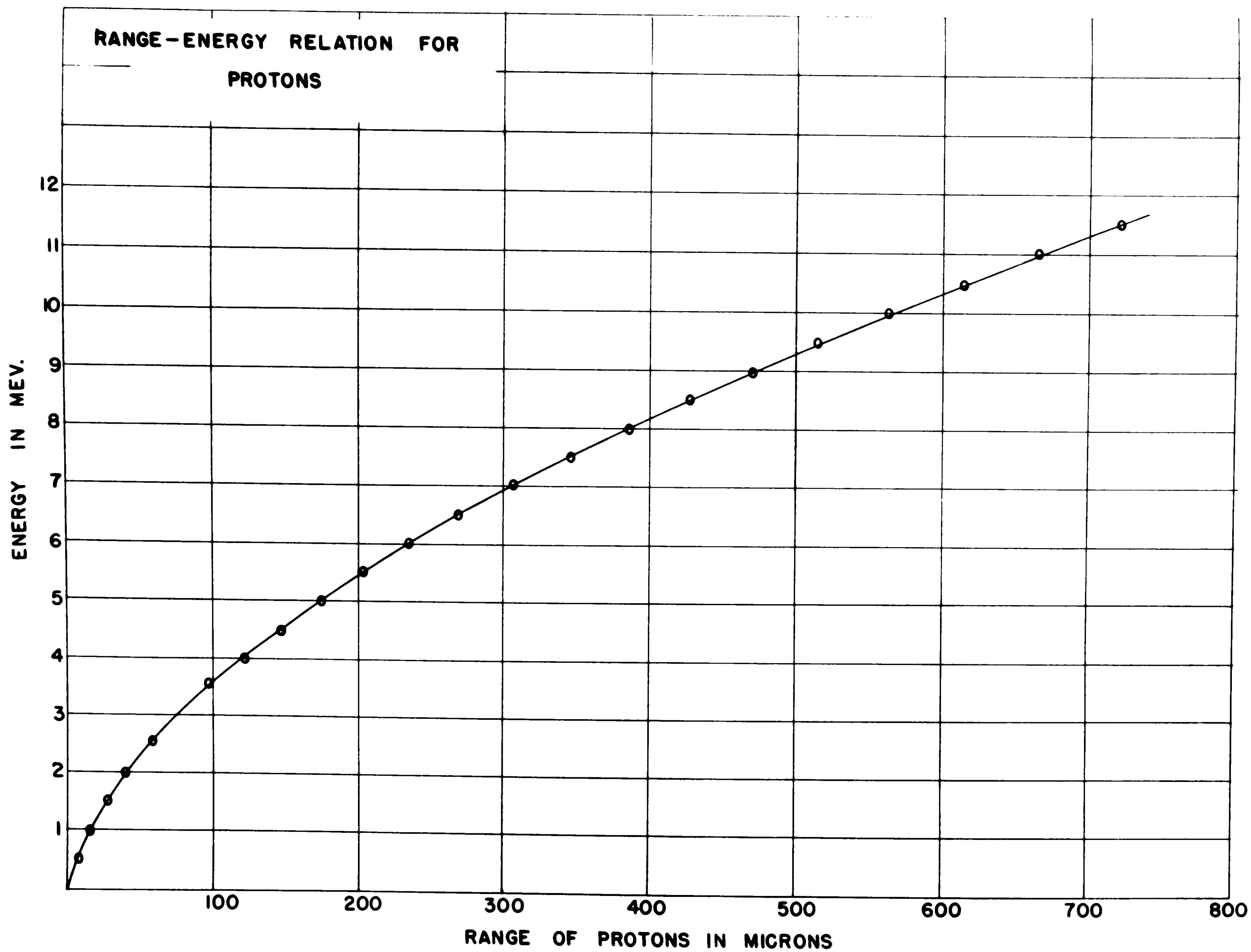
Range Energy Relation for Protons and Alpha Particles in Ilford Nuclear Research Emulsions.

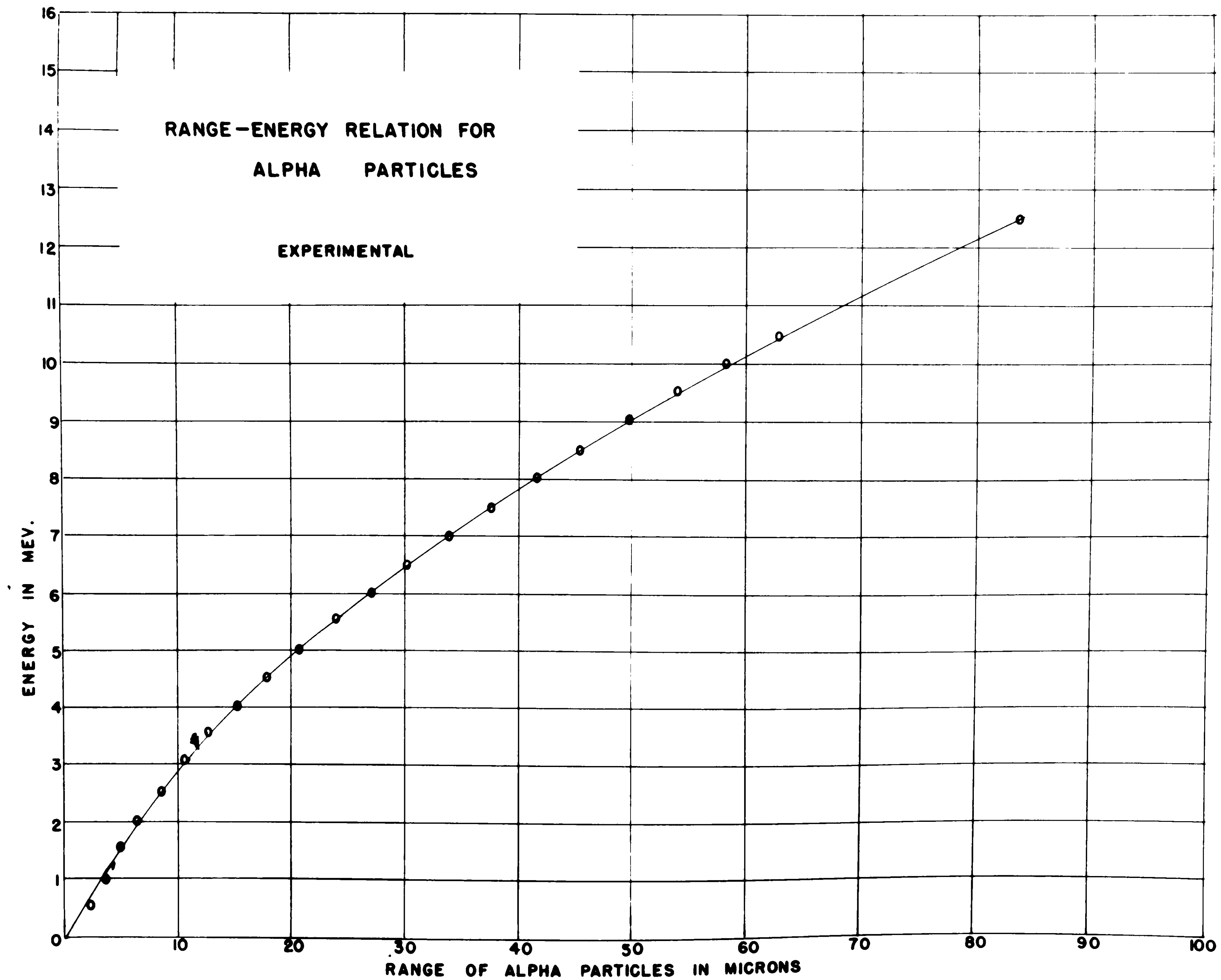
Data from Lattes, Fowler and Cuer, (L9) and Camerini and Lattes (C1).

Energy MeV	Range of protons in μ	Range of -particles in μ	Energy MeV	Range of protons in μ	Range of -particles in μ
0.5	5.5	2.1	7.0	306.0	33.6
1.0	14.5	3.52	7.5	345.0	37.5
1.5	26.0	4.96	8.0	385.0	41.4
2.0	40.0	6.54	8.5	426.0	45.3
2.5	56.5	8.34	9.0	469.0	49.5
3.0	75.0	10.38	9.5	515.0	53.7
3.5	97.0	12.60	10.0	564.0	58.0
4.0	120.5	15.0	10.5	614.0	62.6
4.5	146.0	17.65	11.0	666.0	67.7
5.0	173.0	20.5	11.5	720.0	72.7
5.5	202.0	23.6	12.0	776.0	77.8
6.0	234.0	26.7	12.5	834.0	83.4
6.5	269.0	30.0	13.0	895.0	

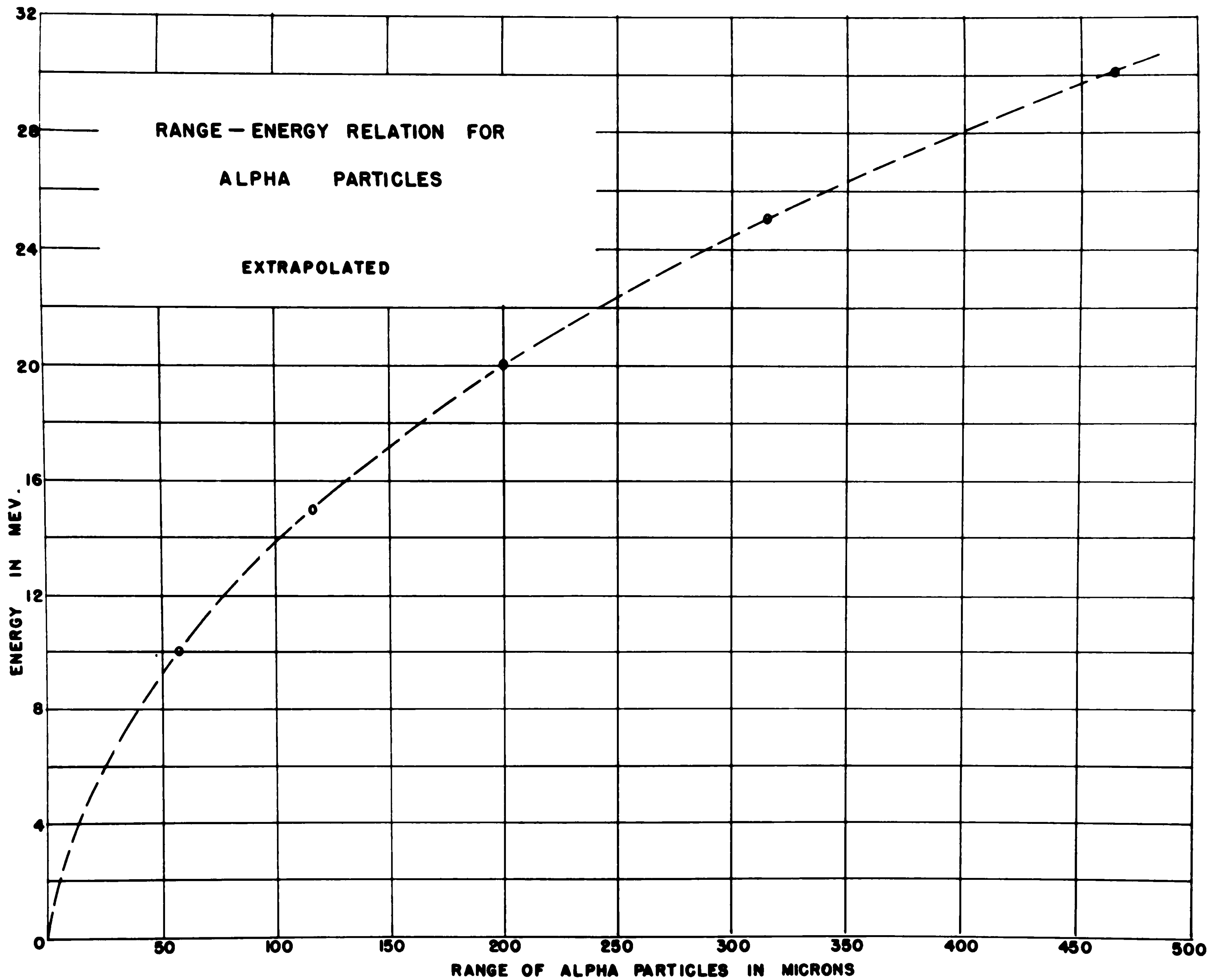
Energy MeV	Range of protons in μ	Range of -particles in μ
10.0	565.0	58.0
15.0	1135.0	117.0
20.0	1870.0	201.0
25.0	2750.0	315.0
30.0	3760.0	464.0
35.0	4925.0	653.0

Precision in the range from 2 to 13 MeV, ±2%. Extrapolated ±8%. These figures apply to B.1, B.2, C.1 and C.2 types. For E.1 the range for a given energy is about 3% less than the value stated.


RANGE-ENERGY RELATION FOR PROTONS
ENERGY IN MEV.
12
11
10
9
8
7
6
5
4
3
2
1
100
200
300
400
500
600
700
800
RANGE OF PROTONS IN MICRONS



RANGE-ENERGY RELATION FOR
ALPHA PARTICLES
EXPERIMENTAL
ENERGY IN MEV.
RANGE OF ALPHA PARTICLES IN MICRONS
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
20
30
40
50
60
70
80
90
100



RANGE — ENERGY RELATION FOR
ALPHA PARTICLES
EXTRAPOLATED
ENERGY IN MEV.
RANGE OF ALPHA PARTICLES IN MICRONS
0
4
8
12
16
20
24
28
32
50
100
150
200
250
300
350
400
450
500

APPENDIX III

Composition of Ilford Nuclear Research Emulsions

Type - Unloaded, normal air dried emulsions.

Element	Gms/cc	% by Wt.	Relative No. of atoms/cc	% by No. of atoms
Ag	1.85	47.3	10.31	12.7
Br	1.34	34.2	10.08	12.4
I	0.052	1.3	0.25	0.3
C	0.272	7.0	13.65	16.8
H	0.056	1.4	33.71	41.6
O	0.266	6.8	10.01	12.3
S	0.010	0.26	0.18	0.2
N	0.067	1.7	2.88	3.6

Type - Lithium loaded, normal air dried emulsions.

Ag	1.80	45.0	10.02	12.4
Br	1.31	32.8	9.86	12.2
I	.051	1.3	.24	.3
C	.262	6.6	13.14	16.2
H	.045	1.1	27.09	33.5
O	.348	8.7	13.09	16.2
S	.071	1.8	1.34	1.7
N	.08	2.0	3.44	4.3
Li	.031	.78	2.67	3.3

Type - Beryllium loaded, normal air dried emulsions.

Ag	1.89	47.1	10.53	13.4
Br	1.37	34.2	10.31	13.1
I	0.053	1.3	0.35	0.3
C	0.276	6.9	13.85	17.6
H	0.049	1.2	29.50	37.4
O	0.263	6.6	9.89	12.5
S	0.016	.40	0.30	0.4
N	0.085	2.1	3.66	4.6
Be	0.008	0.20	0.54	0.7

Type - Boron loaded, normal air dried emulsions.

Element	Gms/cc	% by Wt.	Relative No. of atoms/cc	% by No. of atoms
Ag	1.69	44.8	9.42	11.5
Br	1.22	32.3	9.18	11.2
I	0.046	1.2	0.22	0.3
C	0.248	6.6	12.44	15.2
H	0.051	1.4	30.70	37.5
O	0.355	9.4	13.36	16.3
S	0.009	2.4	0.17	0.2
N	0.061	1.6	2.62	3.2
Na	0.048	1.3	1.26	1.5
B	0.045	1.2	2.46	3.0

Type - Bismuth loaded, normal air dried emulsions.

Ag	1.39	38.2	7.75	9.5
Br	1.01	27.7	7.60	9.3
I	0.039	1.1	0.18	0.2
C	0.327	9.0	16.41	20.1
H	0.047	1.3	28.29	34.6
O	0.435	12.0	16.37	20.0
S	0.002	0.01	0.04	0.04
N	0.062	1.7	2.67	3.3
Na	0.06	1.6	1.57	1.9
Bi	0.268	7.4	0.77	0.9

Type - Deuterium loaded, normal air dried emulsions.

Ag.	1.205	40.8	6.72	8.1
Br	0.875	29.6	6.58	8.0
I	0.034	1.2	0.16	0.2
C	0.38	12.9	19.06	23.0
H	0.044	1.5	26.49	32.0
O	0.33	11.2	12.42	15.0
S	0.001	0.003	0.02	0.02
N	0.053	1.8	2.28	2.8
Deuterium	0.030	1.00	8.96	10.8

APPENDIX IV

Film Holder for Photomicrography

The film holder was made of two pieces of black bakelite, each about 3" by 12" by 3/8" thick, clamped together with screws and holding a piece of film about 2" by 11" between them. An opening about 1¼" by 10" was cut in the upper one and two slides, each as long as the film holder, were fitted so that they were immediately above the film and so that they closed the opening completely when butted tightly against each other. By moving the right-hand slide to the right a short length of film could be exposed and this could be covered again by moving the left-hand slide to the right till it butted against the other again. By successive moves of this kind a series of short lengths of film could be exposed. The tops of the slide were white so that the image of the track was easily seen. A further refinement was made by adding a piece of brass to the end of one slide, so that it projected about half an inch over the other, and by placing a brass runner about an inch wide in the opening above the other slide, so that it was fairly firmly held in place by the pressure of the two vertical portions against the walls while the horizontal piece was just above the slide and at the level of the brass projection on the first slide. In use, the film holder was lined up with the track to be photographed, the image was brought into sharp focus on top of the slide which did not have the brass projection, the runner was moved so that the in-focus part of the image was between it and the projecting brass piece, a shutter in the light beam was closed, the slide on which the image had been focussed was moved till its end, which had been under the projecting brass against the other slide, was now under the brass runner and the shutter was opened to give the required exposure on the film, now visible between the edges of the two pieces of brass. As soon as the shutter closed, the first slide was moved forward till the projecting brass piece on it met the runner. The second slide was now moved back from its position under the runner to meet the first one, and the holder was then ready to have the next length of track brought into focus. The advantage of the runner and projecting strip was that successive parts of a track could be accurately photographed on the strip of film with no gaps and with no overlapping and the exact length photographed was not dependent on the slide being opened just the right amount. A photograph of the film holder is given in Fig. IV-1.

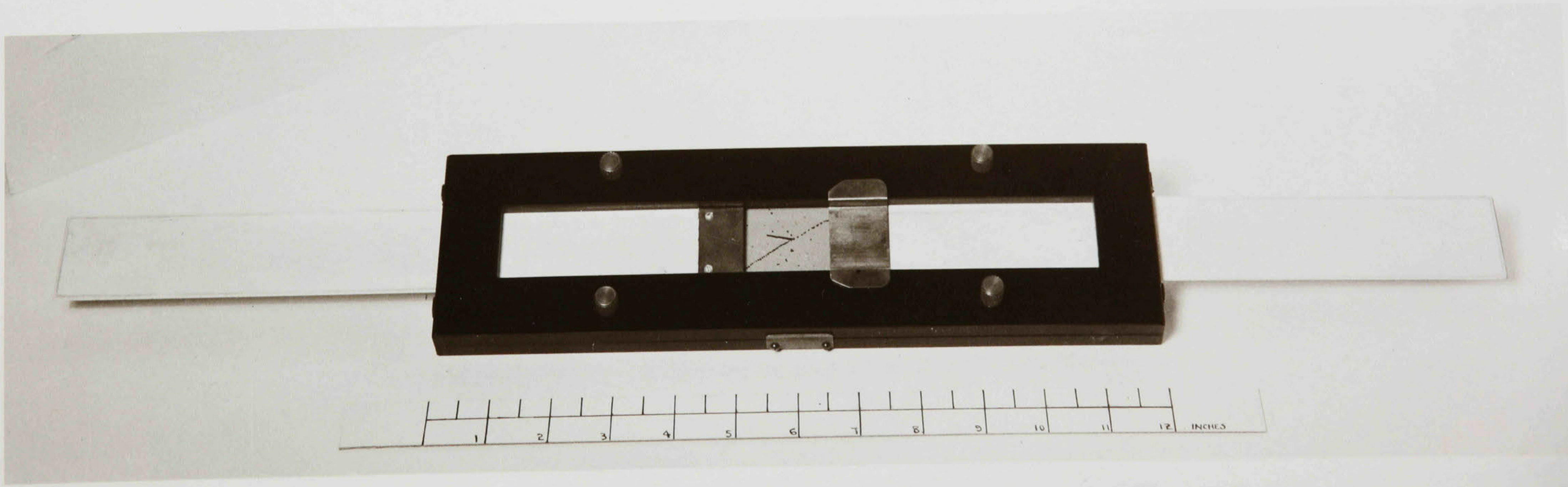


FIGURE IV-1

APPENDIX V

Statistical Summary

Experiment 36

Plate No.	Orientation	Area Searched in cm.^{2}	Emulsion Thick-ness in microns	Emulsion Volume in mm3	Analysis Completed 2	3	4	5	6	7
C2121	Vert.	12.0	50	60.0	x	x				
C2L97	"	12.0	100	120.0	x	x	x	x		
98	"	11.0	100	110.0	x	x	x	x		
99	"	12.0	100	120.0	x	x	x	x		
100	"	12.0	100	120.0	x	x				
C2Be49	"	6.0	100	60.0	x	x				
50	"	6.0	100	60.0	x	x				
B2L61	"	5.97	100	59.7	x	x				
62	"	12.0	100	120.0						
63	"	12.0	100	120.0	x	x				
64	"	12.0	100	120.0	x	x				
C2-126	Horiz.	6.18	50	30.9	x*	x*				
-128	"	11.0	50	55.0	x*	x*	x	x		
C2L101	"	14.63	100	146.3	x	x				
102	"	12.0	100	120.0	x	x				
103	"	12.3	100	123.0	x	x	x	x		
104	"	6.0	100	60.0	x*	x	x	x		
C2Be53	"	12.0	100	120.0	x*	x				
B2L65	"	6.0	100	60.0	x	x				
66	"	6.0	100	60.0	x	x				
C2B116	"	1.35	100	13.5	x	x				

Experiment 36 (cont'd)

C2-130	Control	1.29	50	6.5	x*	x*	x*	x*	x*	x*
-131	"	6.16	50	30.8	x*	x*	x*	x*	x*	x*
C2L106	"	6.05	100	60.5	x*	x	x*	x	x*	x*
107	"	12.0	100	120.0	x	x*	x*	x*	x*	x*
C2Be59	"	6.24	100	62.4	x*	x*	x*	x*	x*	x*
B2L70	"	12.0	100	120.0	x*	x		x*		

Summary of Exposure Time

Altitude	Time: Vertical Plates	Time: Horizontal Plates
Total flying time	348 hours	348 hours
at 10000' or above	202 "	170 "
12000' " "	148 "	126 "
14000' " "	125 "	104 "
15000' " "	108 "	88 "
16000' " "	98 "	79 "
18000' " "	83 "	69 "
20000' " "	14 "	14 "
25000' " "	0.8 "	0.8 "

* None were found.

Experiment 36 (cont'd)

Distribution of stars on each plate by number of prongs

Plate No.	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16 & over
C2121	1	1	2	5											
C2L97	2	10	12	7	3		3		1						
98	9	7	12	7	3		1	3	2	2					
99	7	18	5	5	3	3	2	2						1	
100	8	10	13	3	2	2	1	1			3				
C2Be49	1	8	2	5		2				1					
50	2	3	6	4	2	1		1						1	
B2L61	6	7	3	3	1		2			2					
62	14	12	10	5	4				1						1(26)
63	6	15	7	4	4	2	2	3	1	1					
64	2	7	10	5	5	4	1		2	1					
C2-126															
-128			2	3	3	1				3					
C2L101	7	10	16	6		2	2			3					
102	5	11	12	8	2	4	2	2	1	1					
103	8	5	8	8	3	2		3							
104		3	8	3	1	1		1							
C2Be53		2	4	2	2	2		1	1	1					
B2L65	1	1													
66	1	2	3	1		1									
C2B116	2	4	1				1	1							
C2-130															
-131															
C2L106		1		1				1							
107	2	1													
C2Be59			1												
B2L70		2	1		1	1									

Experiment 41

Plate No.	Orientation	Area Searched in $cm.^2$	Emulsion Thickness in microns	Emulsion Volume in mm3	Analysis Completed 2	3	4	5	6	7
C2-229	Vert.	12.3	100	123.0	x	x	x	x	x	x
230	"	6.60	100	66.0	x	x	x	x	x	
C2B157	"	12.3	100	123.0	x	x	x			
158	"	3.12	100	31.2						
159	"	12.3	100	123.0	x	x				
160	"	12.0	100	120.0	x	x	x	x		
C2D5	"	12.3	100	123.0	x	x	x			
C2L109	"	12.3	100	123.0	x	x	x	x		
E1B121	"	6.6	50	33.0						
E1L73	"	12.3	50	61.5						
C2L116	Control	12.3	100	123.0	x	x	x	x*		
Total: Expts. 36 and 41		358.6		3308.3						

Summary of Exposure Time

Altitude	Time (all plates)
10000' or above	267 hours
15000' " "	187 "
17000' " "	169 "
18000' " "	137 "
19000' " "	80.5 "
20000' " "	15.3 "
25000' " "	0.4 "

* None were found.

Experiment 41 (cont'd)

Distribution of stars on each plate by number of prongs

Plate No.	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16 & over
C2-229	6	7	22	8	3	5	2	1					1		
-230	7	9	6	6	2	2		2		1		1	1		
C2B157	16	24	26	14	6	6	1	2	1	1		1			1 (23)
158	5	7	6	1	2	1	1								
159	7	21	17	11	6	4			2	2	3			1	
160	9	27	20	13	7	2	6	1							
C2D5	1	11	7	2	3	1				1			1	1	1 (21)
C2L109	8	21	17	6	6	4	4	3	2	1	1				
E1B121	2	3	2	2	1	1	1				1				
E1L73	4	1	5	1	3		1		1						
C2L116	1	1	2			1									
Total Expt. 36 and 41.	150	272	268	149	78	55	36	28	15	21	8	2	3	4	3

APPENDIX VI

Photographs of pages of typical records are shown in Figs VI-1 and VI-2.

The data given in the first column of the search record is to establish accurately the conditions under which the search was conducted.

The scheme followed in recording the analysis is outlined below and may be seen in operation in the record pages which were taken from "Analysis of three-pronged cosmic stars" (A3pcs.), C2L109.

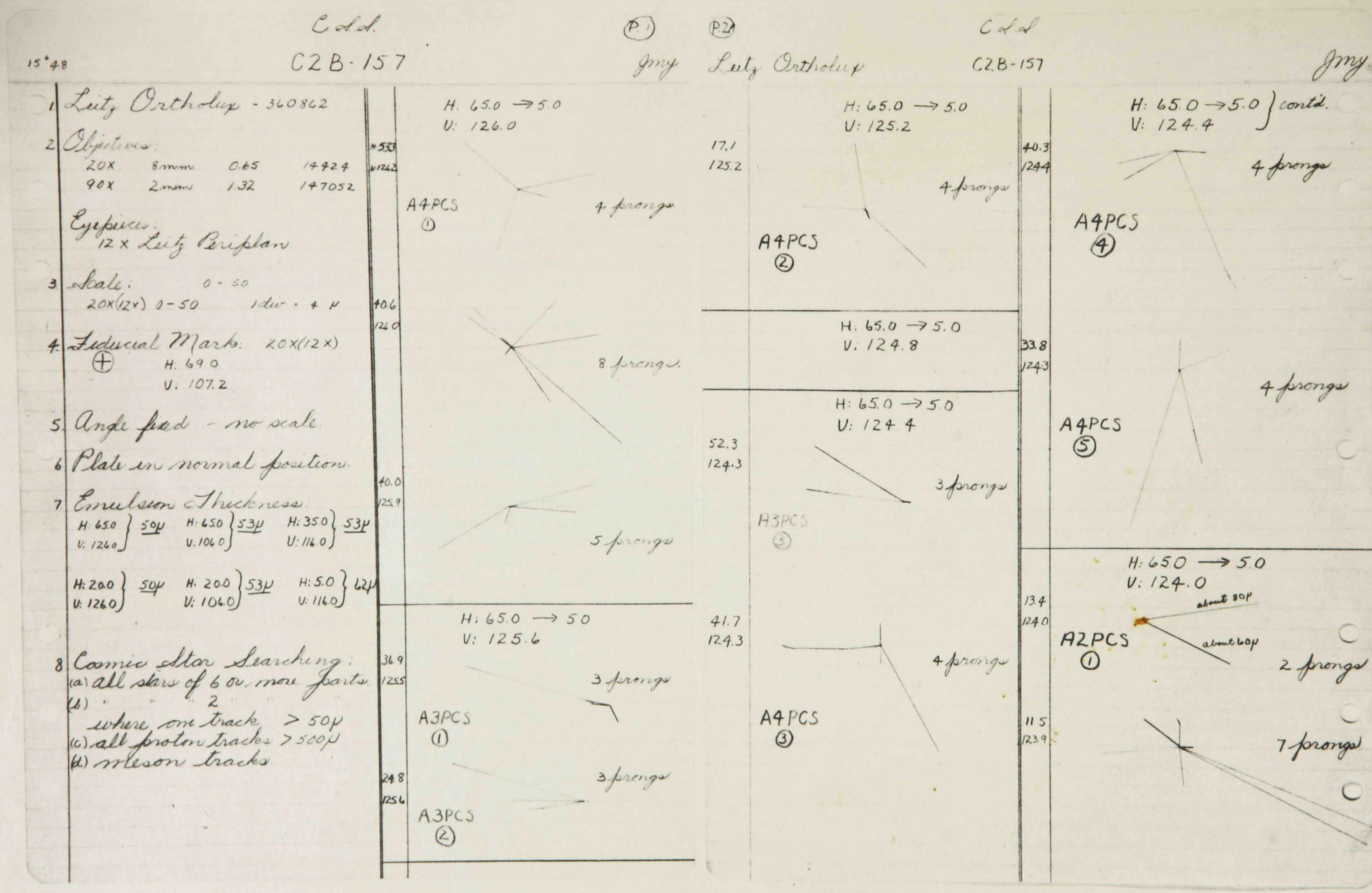
ANALYSIS

A. Description of event
   1 Position of vertex, emulsion, glass or air.
   2 End of tracks, emulsion, glass or air.
   3 Length of tracks, particularly those ending in the emulsion.
   4 Oddities in event.
      -hammer tracks
      -split tracks
      -large stars completely in emulsion
      -two particles in opposite directions.

B. Identification of Tracks
      -take account slant, aging and decrease in grain density near glass or air.
   1 Proton
      -compare with proton recoil
      -note grain density and direction of increase
      -note breaks in track.

   2 α particles
      -compare with known particles in contamination tracks
      -note grain density and direction of increase
      -note break in track.

   3 Meson - in or out of stars
      -note scattering
      -note any sharp increase in grain density near end of track.



C.d.d.
P1
C2B-157
15*48
Jmy
1 Leitz Ortholux - 360862
2 Objectives:
20X 8mm 0.65 14424
90X 2mm 1.32 147052
Eyepieces:
12 x Leitz Periplan
3 Scale: 0 - 50
20X(12X) 0-50 1 div = 4 μ
4. Fiducial Mark: 20X(12X)
H: 69.0
V: 107.2
5. Angle fixed - no scale
6 Plate in normal position
7 Emulsion Thickness:
H: 65.0 V: 126.0 50μ
H: 65.0 V: 106.0 53μ
H: 35.0 V: 116.0 53μ
H: 20.0 V: 126.0 50μ
H: 20.0 V: 106.0 53μ
H: 5.0 V: 116.0 62μ
8 Cosmic Star Searching:
(a) all stars of 6 or more parts
(b) " " 2
where one track > 50μ
(c) all proton tracks > 500μ
(d) meson tracks
H 53.3
V 126.2
H. 65.0 → 5.0
V: 126.0
A4PCS
1
4 prongs
40.6
126.0
8 prongs
40.0
125.9
5 prongs
H: 65.0 → 5.0
V: 125.6
36.9
125.5
3 prongs
A3PCS
1
24.8
125.6
3 prongs
A3PCS
2
P2
Leitz Ortholux
C.d.d.
C2B-157
Jmy
17.1
125.2
H: 65.0 → 5.0
V: 125.2
4 prongs
A4PCS
2
H: 65.0 → 5.0
V: 124.8
H: 65.0 → 5.0
V: 124.4
52.3
124.3
3 prongs
A3PCS
3
41.7
124.3
4 prongs
A4PCS
3
40.3
124.4
H: 65.0 → 5.0
V: 124.4
contd.
4 prongs
A4PCS
4
33.8
124.3
4 prongs
A4PCS
5
H: 65.0 → 5.0
V: 124.0
13.4
124.0
about 80μ
about 60μ
A2PCS
1
2 prongs
11.5
123.9
7 prongs

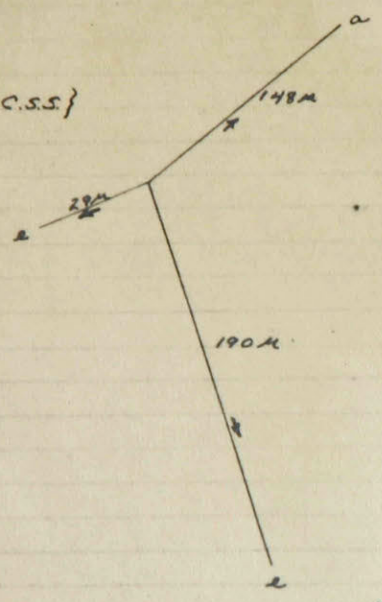
FIGURE VI-1

C2B-160 14/7/48 A3pcs-7 BJm

Zeiss Research
90x(15x) 0-100

10x5
4.4

{pg 4 - C.S.S.}



A 1. vertex in emulsion
2. ends of tracks - see diagram
3. lengths of tracks - see diagram
4. no oddities

B 1. Grains are quite close together, running together in little clumps as particle moves away from vertex.
- slants quite steeply in em.
- probably proton track that ends in air

2. Grain count in last 50µ - 71 grains
Grain count in next 50µ - 66 grains
This track does not have any heaviness at the end, but the grain count of 50µ at vertex is 57 which indicates that the particle is probably moving outwards from vertex
Grains are close together throughout track
- on horizontal plane
- medium weight proton track

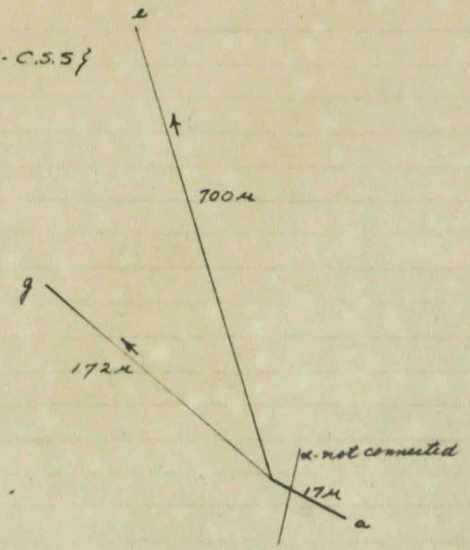
3. Grains run together in small groups from about 3 to 6 grains in each group.
- α particle

C2B-160 14/7/48 A3pcs-8 BJm

Zeiss Research
90 x (15x) 0-100

81.1
5.05

{pg 4 - C.S.S.}



A 1. vertex in emulsion
2. ends of tracks - see diagram
3. lengths of tracks - see diagram
4. no oddities

B 1. Track is very heavy: solid throughout except for a little break near vertex - probably α

2. Grains are spaced very close together near vertex and as particle moves outwards grains run together in little groups
- light proton track travelling outwards from vertex

3. Grain Count in last 50µ - 60 grains
Grain Count in next 50µ - 50 grains
- almost on horizontal plane
- a little small angled scattering
- could be meson

FIGURE VI-2