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ABSTRACT

The first observed production of negative cascade particles at an accelerator is reported. A 30-inch propane bubble chamber was exposed to a beam of negative pions of 5.5 Bev/c. Two cascades were identified, indicating a production cross section of $2.3^{+3.1}_{-1.6}$ μb. The Q values found were 49.5 ± 7.9 Mev and 53.6 ± 11.3 Mev. The lifetimes were $1.9 \pm 0.1 \times 10^{-10}$ sec and $5.2 \pm 0.4 \times 10^{-10}$ sec. Both Ξ's were produced backwards in the center-of-momentum system. The identification process and background is discussed.

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I. INTRODUCTION

The cascade particle was first observed in a cloud chamber by the Manchester group.[1] However, at that time there was considerable uncertainty as to the nature of this new particle, since they were unable to identify the V^0. Anderson et al.[2] established that the V^0 was a Λ. Later Armenteros et al.[3] were able to definitely identify the negative secondary as a pion. Most of the subsequent data have also come from cloud chamber observations of cosmic-ray events. There have been some data reported from emulsion stacks exposed to cosmic rays, but the evidence is less conclusive, since the Λ can not usually be found. Because so few cascades have been observed, very little is known about the particle other than the existence of the one decay mode, which has been well established. A good summary of our knowledge of cascades is reported in a general strange-particle review article by Franzinetti and Morpurgo.[4]

The production of cascade particles by 5.5-Bev/c pions in propane is reported here as the first observation of cascade production by an accelerator.

II. EXPERIMENTAL ARRANGEMENT

A 30-inch propane bubble chamber operated in a 13-kilogauss magnetic field[5] was exposed to a 5.5-Bev/c beam of negative pions from a beryllium target located 14° upstream from the west straight section of the Bevatron.

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*This work was done under the auspices of the U.S. Atomic Energy Commission.

Negative pions at 0° from the beam were deflected by the Bevatron field through a thin window in the vacuum tank. Two 8-inch quadrupole magnets were used for focusing, adjusted to give an image at the chamber of the target 1 inch high and 2.8 in. wide. An analyzing magnet deflected the beam 7.2°, so that 5.5-Bev/c pions arrived at the center of the chamber. The dispersion was 80 Mev/c per inch, and the uncertainty at any point due to the target size was ± 125 Mev/c. The total distance from the target to the center of the chamber was 56 feet. Figure 1 shows the experimental arrangement.

All together, 31,500 stereo pairs of pictures were taken on 70-mm film. The film was scanned for all V^0's with origins visible in the chamber. The scan cards were examined for possible cascade decays, and these events were then examined by a physicist. Those events in which the V^0 could have possibly come from a kink in a secondary track and which lay on the opposite side of the secondary track from the deflected track were measured. The possible cascade decays were not restricted to negative particles. Fifteen events satisfied the visual-appearance criterion, two of them positive.

Two methods of measuring were used, and most events were measured by both. One method was to reproject through an optical system similar to that used on the chamber but with air replacing the propane. A correction for the index of refraction of propane was made. The tracks in the two views were recombined on a ground-glass screen, and angles and curvatures were measured. The curvatures were measured by fitting templates to the tracks in space. The other method of measuring was by the use of a digitized microscopes measuring directly on the two negatives. The locations of a series of points along a track in each view were punched directly onto IBM cards. These cards were then processed by an IBM 650 calculator which gave an output of momenta and angles, with errors based on the internal consistency. Allowance was made for the errors in curvature caused by multiple scattering in the propane. The agreement between the two methods of measuring was compatible with the errors given in each case.

III. IDENTIFICATION

Of the fifteen events submitted for measurement, only two were found to be consistent with the known properties of a cascade. They are shown in Figs. 2 and 3. The other events are discussed in a later section. For an event to be considered a cascade the following criteria had to be satisfied.

(a) The V^0 had to be identified as a Λ.

(b) The plane of the Λ had to contain the cascade decay point.

(c) The plane of the cascade and its decay pion had to contain the decay point of the Λ.

(d) Transverse momentum of the Λ had to balance about its line of flight.

(e) Transverse momenta of the pion and the Λ at the cascade decay point had to balance.

(f) The relative ionization had to be consistent with the assumption of a cascade decay.

(g) The kinematics had to be compatible with the assumption of

$$\Xi^- \rightarrow \Lambda^0 + \pi^- + \sim 66 \text{ Mev}.$$

Criterion (a) rules out the identification of possible $\Xi^- \rightarrow n + \pi^-$ modes. Criteria (c), (e), and (g) would eliminate possible leptonic decay modes of cascades.

In general it is not always possible to distinguish a Λ from a θ^0. No event was rejected solely because the V^0 could not be positively identified as a Λ. However, in both the identified cascades, the V^0 was definitely established as a Λ. In one case (17776) the Λ was identified readily because the positive prong was a stopping proton, and the measured Q value was 35 ± 6 Mev. In the other case (49837) the measured Q on the assumption of a Λ was 31 ± 7 Mev and on the assumption of a θ^0 was 180 ± 21 Mev, so that the fit to a Λ on Q value alone was better than to a θ^0. Ionization estimates from gap counting were decisive for the positive prong's being a proton rather than a positive pion.

Both events satisfied the two coplanarity requirements within the errors. Coplanarity was checked visually on the space reprojector by actually fitting the planes in question, and by spatial reconstruction from the microscope measurements. Both events satisfied transverse momentum balance to within 1.3 standard deviations or less from the unadjusted values. Table I shows the amount of unbalance and the errors. Later an adjustment was made to give exact transverse momentum balance.

In both events the ionization of the tracks was consistent with the particle identities of a cascade decay. Ionization was estimated from comparison with tracks of known ionization in each picture. The positive tracks of the Λ's could be identified as heavier than pions, and the cascade track in 49837 was definitely heavier than a K^-.

Finally, the Q values calculated for the two events agreed satisfactorily with the present value of 66 ± 3 Mev.[6]

The only reasonable possible alternative interpretation of both events is $\Sigma^- + n \rightarrow \pi^- + \Lambda + n$, where the outgoing neutron and carbon recoil must have their resultant momentum in essentially the forward direction. Because of the Fermi momentum of the neutron before the reaction and the two unknown outgoing momenta of the neutron and carbon recoil, the problem does not lend itself readily to calculation. If the assumption of an essentially free neutron is made, then a Σ^- of 815 Mev/c would satisfy the visible kinematics for 17776. This interpretation cannot be excluded on the grounds of measured momentum, since the track in question was too short to measure, or on the grounds of ionization, whose estimation was [illegible]

Table I

The measured momenta and angles and the constrained values for the various tracks of the two events are given. The track numbers are the same as in Figs. 2 and 3. ϕ_{ij} refers to the angle between Track i and Track j. The adjustment parameter τ is the adjustment in a variable divided by the measurement error for in that variable. The value listed in brackets under measured momentum for Track 5 is the value calculated from the constrained Λ variables. The transverse momentum unbalance at the four decay points is given. The sum of the squares of the adjustment parameter, $\Sigma(\tau_i)^2$, which indicates the reliability of the adjustment, is given.

Event	Track No.	Measured momentum (Bev/c)	Constrained momentum ()Bev/c)	τ	Angle No.	Measured value (degrees)	Constrained value (degrees)	τ
					[illegible]	[illegible]	83.6	-0.25

grounds of ionization, since saturation was reached in this picture at a relative ionization of about two. In 49837, an incoming Σ^- of 1180 Mev/c could satisfy the visible kinematics. This situation is close enough to the observed momentum and ionization that it may not be excluded. However, it is improbable that two events would occur with their charged prongs satisfying all the identification criteria for cascades. Thus it is concluded that the events in question are cascade decays.

IV. RESULTS

The following constraints were applied to reduce the errors due to the measurement uncertainties in calculating the Q values of the cascade decays. The momenta and angles of the Λ-decay products were adjusted to give a Q for the Λ of exactly 37.4 Mev and to satisfy transverse momentum balance and coplanarity with respect to the cascade decay point. These adjustments were made with the requirement that the sum of the squares of the adjustments in a variable divided by the measurement error for that variable be a minimum. The Λ momentum was calculated from the adjusted values. At the cascade decay point the adjustment required transverse momentum balance and coplanarity for the Λ and π^- with respect to the cascade-particle line of flight. The amounts of the adjustments are shown in Table I. The Q values of the cascades were then calculated from these adjusted values. Derivatives of the Q value with respect to its parameters were taken. These derivatives were then multiplied by the uncertainties in the variables, and a square root of the sum of the squares was taken to give the error in the Q value.

The Q values thus obtained were 49.5 ± 7.5 Mev for event 17776, and 53.6 ± 11.3 Mev for 49837. The errors are approximately one standard deviation. The times for each particle's life in its own rest system were

$1.9 \pm 0.1 \times 10^{-10}$ sec for 17776 and $5.2 \pm 0.4 \times 10^{-10}$ sec for 49837.

A production cross section for cascades was found in the following manner. The number of beam-pion tracks entering the scanning region in every hundredth picture was recorded, as well as the number of usable pictures. A picture was considered unusable if there were too many tracks in it for efficient scanning. In some pictures parts of the chamber were not visible, owing either to partial failure of the lights or to a residual bubble. In these cases a suitable correction was made. Not all the tracks entering the scanning region traverse its entire length, since parts of some tracks are removed by interactions. A 10% correction for this effect was made, based on a mean free path of 206 ± 30 cm for all beam-pion interactions in propane. A 6% correction was made for the muon contamination due to decays in flight of the pions. From these figures the path length traversed by the pions was determined.

The scanning efficiency for cascades was estimated as follows. Scanners were instructed to search for V^0 particles and to indicate whether the V^0 particle appeared to be produced in the wall of the chamber or in the propane. The combined efficiency for finding V^0 particles from visible beam interactions, as determined from two or more successive scans by different scanners, was 85 ± 5%. It was felt that the efficiency for associating a V^0 with a kink in a secondary track would be less than for associating it with a beam interaction. A check of one-eighth of the pictures scanned revealed no cases in which a V^0 should have been associated with a kinked secondary track and was not. This check indicated that the scanning efficiency for cascades was not much lower than for V^0's. A lower limit of 50% was chosen to be conservative. Accordingly, the efficiency for finding cascades was estimated to be 70^{+10}_{-20} %.

Since cascades in which the Λ particles decay via the neutral mode would not be detected by the procedure used, a correction based on the branching ratio for Λ decay was made.

From these figures the mean free path for the production of a cascade in propane was found to be 3.2×10^6 cm.

An $A^{2/3}$ law was assumed for the shielding of the nucleons in carbon, and a cross section per nucleon of $2.3^{+3.1}_{-1.6}$ microbarns was obtained. Almost all the error is due to the poor statistics of the small number of events, and represents a confidence coefficient of 0.84.

Since indications are that the lifetime of the Ξ^- is on the order of 1 to 10×10^{-10} sec, a lifetime correction to the cross section is probably not large for a chamber of this size. A lifetime much different from this would require a considerably correction. No correction was made for possible alternative decay modes. A decay mode with a strangeness change of two, namely $\Xi^- \to n + \pi^-$, would not have been found by the scanning method. used. Any leptonic decay modes would have been rejected by the identification criteria used. This last correction might be on the order of a factor of two, since the leptonic decay rate based on a universal Fermi interaction has been calculated to be possibly of the same order as that for pionic decays.[7]

Both production events were known to have occurred in carbon, since the net outgoing charge was different from zero in both cases. In one event (17776), there were six outgoing charged prongs, two positive and four negative. Only one particle was identifiable by ionization, and that was a negative pion. There were no visible neutral or charged decays associated with the event. Event 49837 had only one outgoing charged prong, that of the cascade itself. There was a θ_1^0 decay associated with the production origin. An analysis for the missing momentum and energy indicated that the kinematics were consistent with there being another particle of a K mass. Thus the observations reported here do not contradict the assignment of $S = -2$ for the cascade. Both particles were produced strongly backwards in the center-of-momentum system. One (17776) was at a c.m. angle of about 170 degrees, and the other was at an angle of about 160 degrees.

In addition to the above two events, there was another (46709) that may be interpreted as a cascade, although a K^- or Σ^- decay cannot be ruled out. It is shown in Fig. 4. The production event had six charged prongs with zero net charge. The decay event showed a heavily ionizing negative particle emitting a π^- which then came to rest, allowing an accurate momentum determination to be made. The momentum found was 131 ± 4 Mev/c, and the decay angle, $99^\circ \pm 2^\circ$ in the laboratory system. If it is assumed that the decaying particle came to rest or nearly to rest, then these figures are compatible only with a cascade decay. The track was too short for measurement of its momentum, and was at an angle of 43° from the horizontal, so that ionization is difficult to estimate. If the momentum at the decay point is considered a variable, then the decay kinematics are also consistent with both a $K^-_{\pi 2}$ and a Σ^-. A $K^-_{\mu 2}$ decay can be ruled out because the ionization of a $K_{\mu 2}$ would not have been consistent with that observed. The other five tracks from the production event were long enough for good momentum measurement, so that a kinematical analysis of the production event was feasible. The kinked positive track was identified by ionization as a π^+. There were no visible associated decays. Visible transverse momentum was out of balance by about 750 Mev/c, implying at least one neutral particle. Under the assumption that the production event was in hydrogen, energy and momentum conservation could be satisfied only by stretching the measured values somewhat beyond the experimental errors, and then only for the assumption of a $K^-_{\pi 2}$ decay. If the production event is assumed to be in carbon, then the kinematics become far less definitive because of the unknown carbon recoil, and they are consistent with all three of the possible identities of the decaying particle. The $K_{\pi 2}$ assumption is unlikely on grounds of lifetime, since the particle would have traveled only 0.015 of a mean life. It is not believed that this event is definitely determined to be a cascade, but it is interesting to speculate that with two cascades found with charged Λ decays, one with a neutral Λ decay should be present. The evidence for the interpretation of this decay as a cascade is of such a nature that it has not been included in any of the statistics.

V. BACKGROUND

Most of the background events could be rejected for failure to comply with two or three of the requirements demanded for cascade identification.

Table II lists the background events and indicates which of the identification criteria were not satisfied. The identity of the V^0 is given whenever possible. The proper classification of these background events is difficult. In both the positive cases the events are probably K^+ charge exchange: $K^+ + n \rightarrow p + \theta^0$. In two of the events the V^0 particles could be identified as Λ's, and in five of them as θ_1^0's. In the other six cases no definite identification was possible. In one event the incoming track appeared to be a Σ^-, by ionization. Most of the events probably represent strange-particle interactions of various sorts ("strangeness exchange"), although the two with identified Λ's might possibly be leptonic decays of cascades. Some of the events could be interactions of secondary pions producing strange particles.

Table II

Listing of the background events. The sign of the supposed cascade and the identification criteria not satisfied are indicated. The identity of the V^0 is given in those cases in which identification could be made.

Event number	Sign of particle	V^0 not a Λ	Not coplanar	Transverse momentum unbalance	Ionization not consistent	Kinematics not satisfied	V^0 identity
07529	+	x			x	x	θ^0
27777	-	x				x	θ^0
28242	-		x	x		(a)	Λ
28774	-					x	?
30343	-	x	x	x	x	(a)	θ^0
33270	-	x				x	?
39057	-	x		x		(a)	?
39915	-	x				x	θ^0
42072	-			x		x	?
45502	-			x		(a)	?
45781	+	x			x	(a)	θ^0
46155	-			x		(a)	Λ
49697	-			x		x	?

(a) No kinematical calculation was made since it was already apparent that the event was not a Ξ.

VI. ACKNOWLEDGMENTS

The authors wish to acknowledge the assistance of Dr. Edward Lofgren and the Bevatron staff and thank them for their cooperation during the run. The assistance of all the members of the Cloud Chamber group has been indispensable. Special mention should be made of Dr. Robert Birge for setting up the beam, Howard White for the IBM programming and data reduction, and David Hotz for the cross-section normalization and scanning evaluation.

REFERENCES

1. R. Armenteros, K. H. Barker, C. C. Butler, A. Cachon, and C. M. York, Phil. Mag. <u>43</u>, 597 (1952).
2. C. D. Anderson, E. W. Cowan, R. B. Leighton, and V. A. J. van Lint, Phys. Rev. <u>92</u>, 1089 (1953).
3. R. Armenteros, B. Gregory, A. Lagarrigue, L. Leprince-Ringuet, F. Muller, and C. Peyrou, Suppl. Nuovo cimento <u>12</u>, 327 (1954).
4. C. Franzinetti and G. Morpurgo, Suppl. Nuovo cimento <u>6</u>, 565 (1957).
5. W. M. Powell, W. B. Fowler, and L. O. Oswald, Rev. Sci. Instr., in press.
6. G. H. Trilling and G. Neugebauer, Phys. Rev. <u>104</u>, 1688 (1956).
7. G. Morpurgo, <u>Proceedings of the Turin Conference</u>, 1956.

CAPTIONS

Fig. 1. Experimental arrangement for directing π^- beam (from Be target in Bevatron) into propane bubble chamber. A and B are 8-inch quadrupole magnets. C is a 5-foot deflecting magnet. The magnet surrounding the bubble chamber is not shown.

Fig. 2. Event 17776. Track 0 is the beam π^-. Track 1 is the Ξ^- and 2 is the decay π^-. Track 3 is the proton from the Λ decay which stops in the chamber. Track 4 is the π^- from the Λ decay and leaves the chamber at the top glass. Line 5 is the Λ line of flight.

Fig. 3. Event 49837. Track 0 is the beam π^-. Track 1 is the Ξ^- and 2 is the decay π^-. Track 3 is the proton from the Λ decay, and 4 is its π^- which leaves at the bottom glass. Line 5 is the Λ line of flight. Tracks A and B are the π^+ and π^- from a θ_1^0 decay.

Fig. 4. Event 46709, a possible Ξ^- decay without a visible Λ decay. Track 0 is the beam π^-. Track 1 is the possible Ξ^-. Track 2 is a stopping π^- from Track 1. Track A is probably a π^- by ionization. Tracks B and C are positive and could be protons, π^+'s, or K^+'s. Track D is a π^+ which scatters and which was identified by ionization. Track E is a π^- which leaves the chamber. F is an electron pair associated with the production origin.

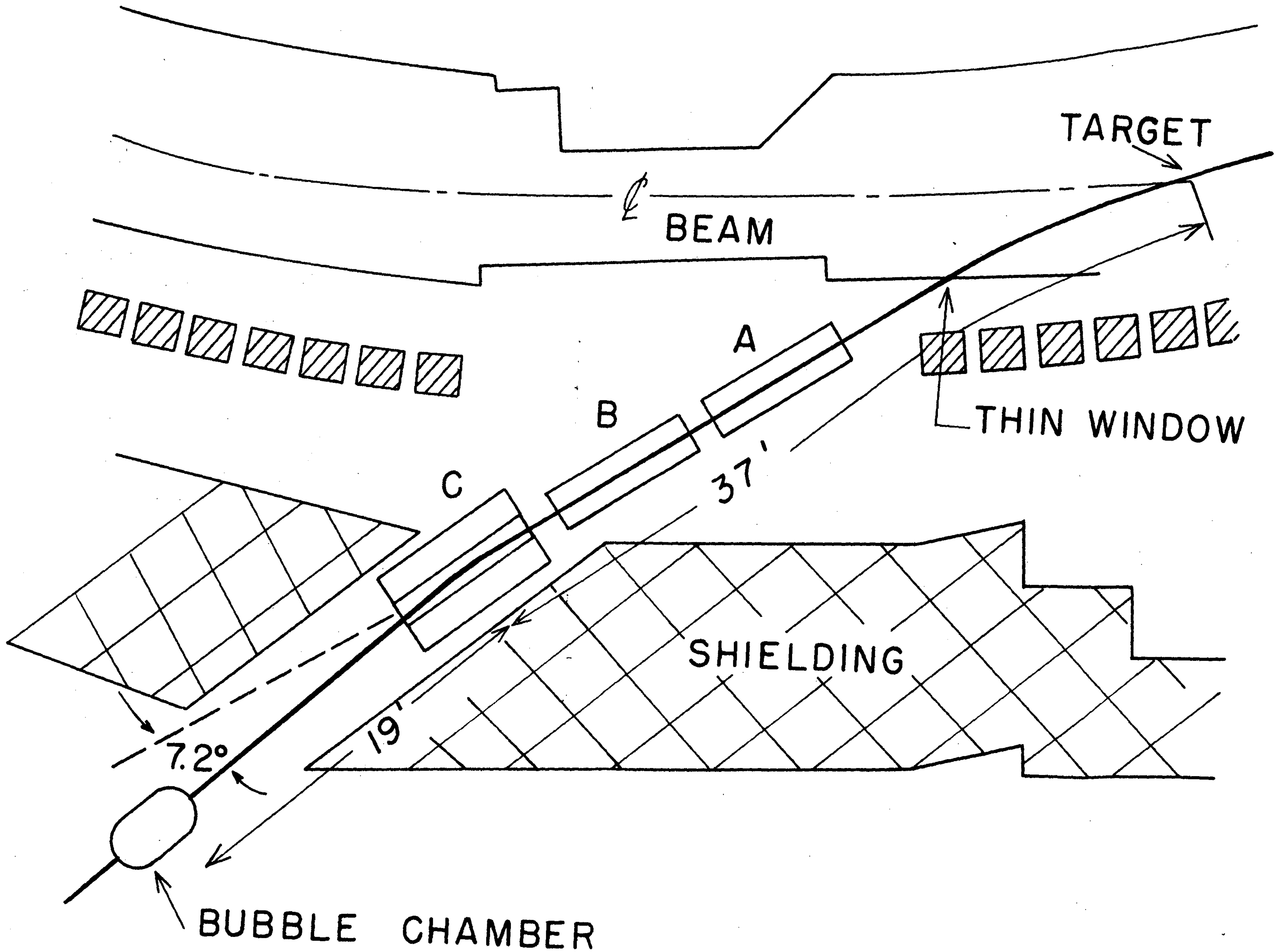

TARGET
℄
BEAM
A
B
C
THIN WINDOW
37'
SHIELDING
19'
7.2°
BUBBLE CHAMBER

FIG 1

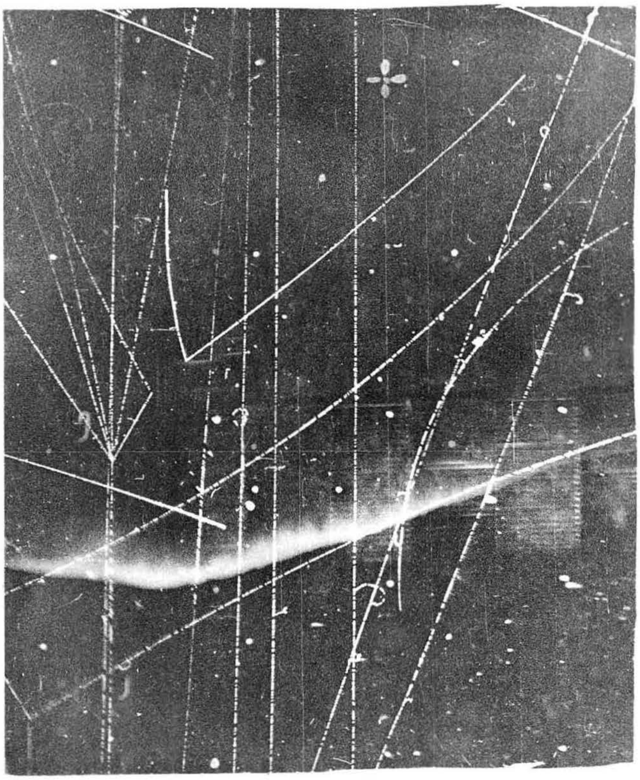
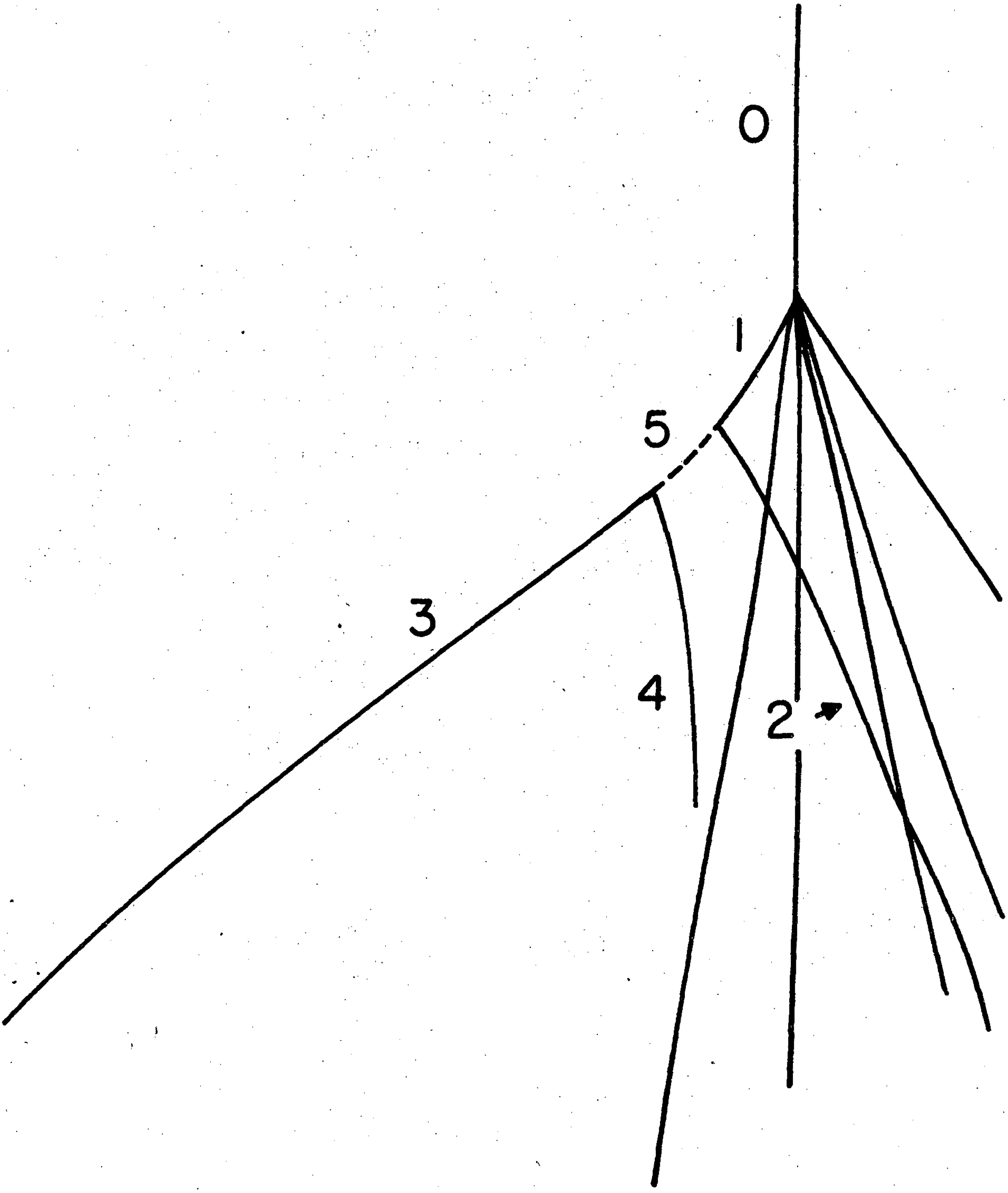


Fig. 2a.

2(b)



51,369-1

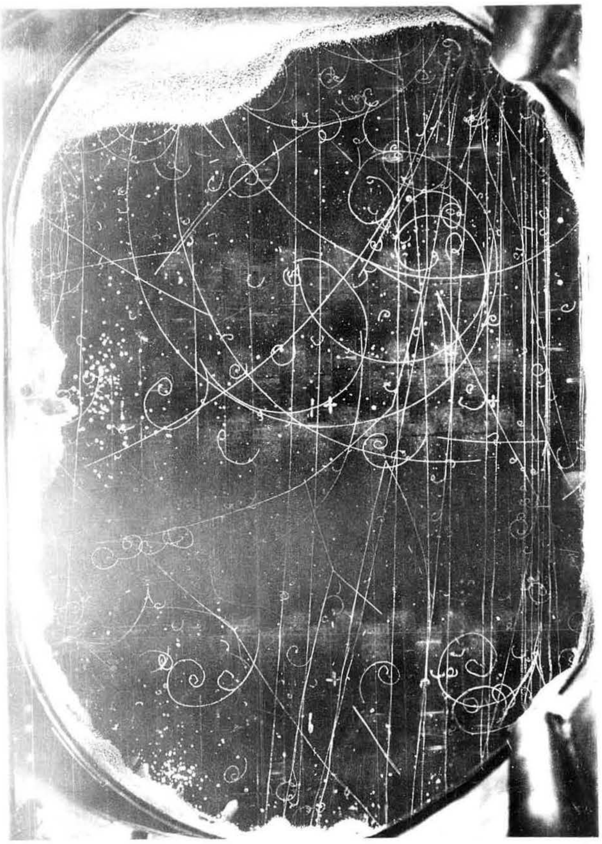
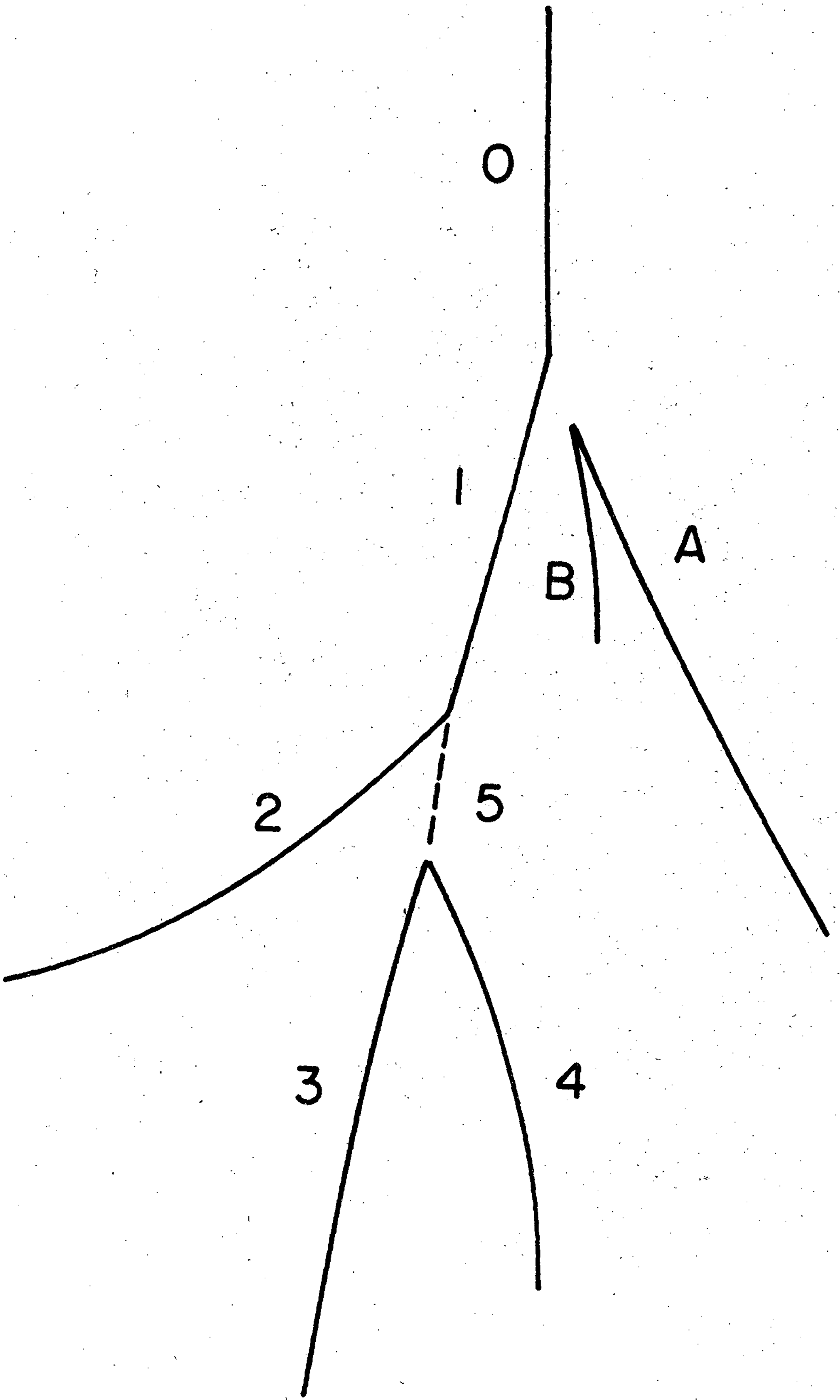


Fig. 3a



3(b)

5L 370-1

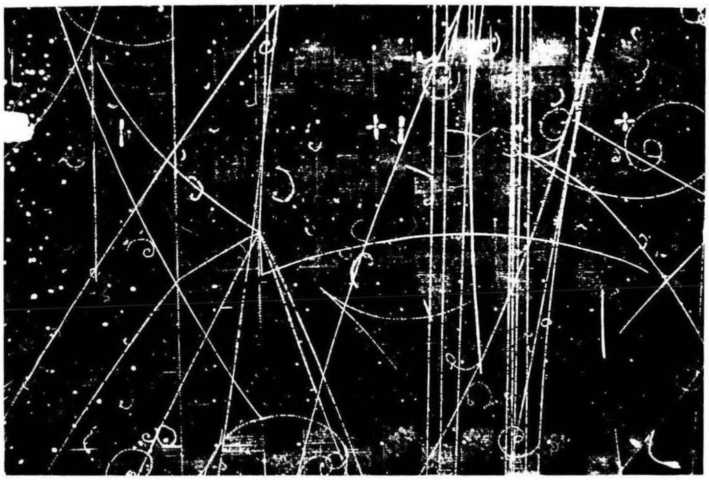


Fig. 4a

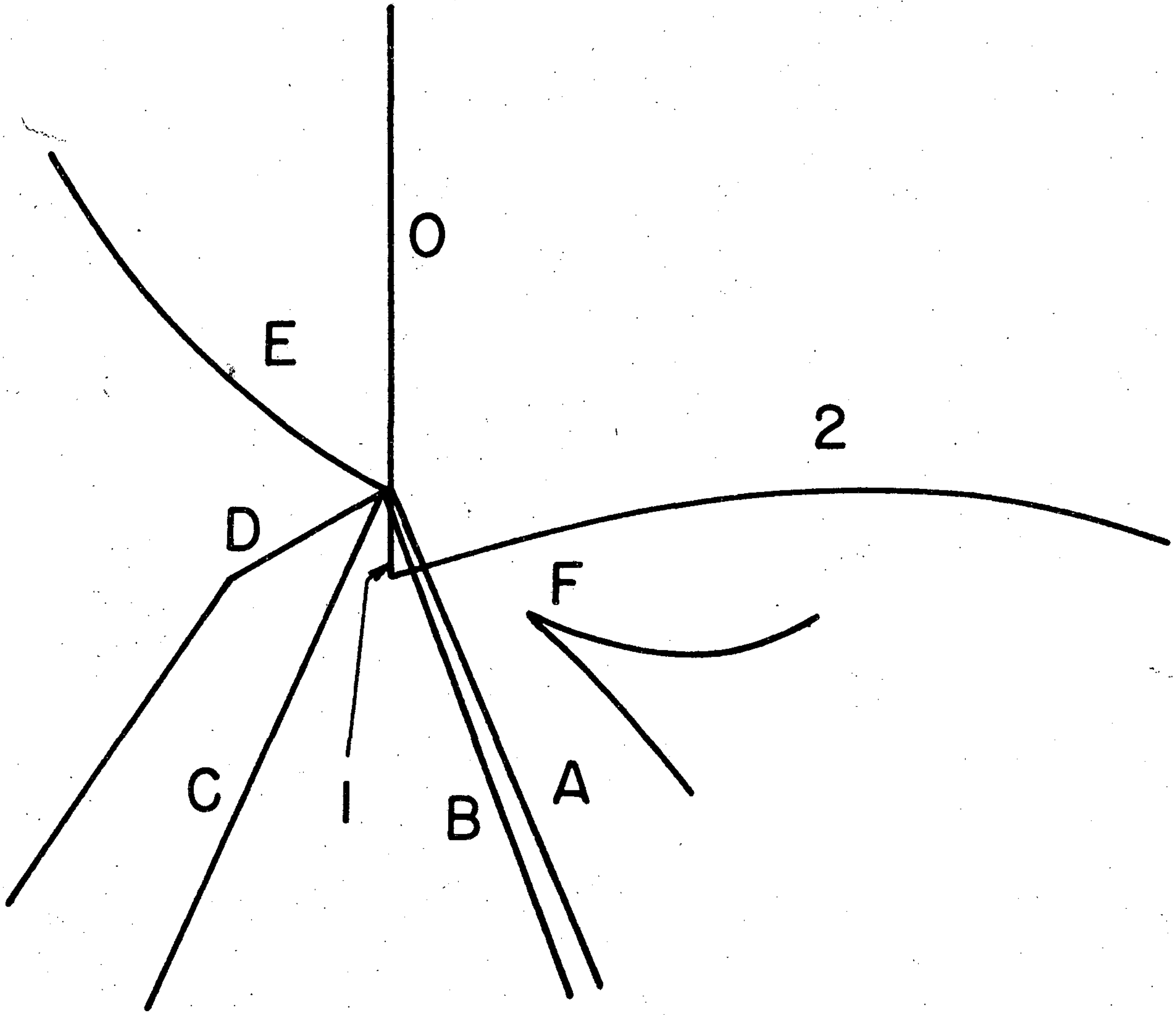


Fig 4b

65