UCRL-1939
UNCLASSIFIED

UNIVERSITY OF CALIFORNIA — BERKELEY

TWO-WEEK LOAN COPY

This is a Library Circulating Copy which may be borrowed for two weeks. For a personal retention copy, call Tech. Info. Division, Ext. 5545

RADIATION LABORATORY

UCRL-1939 c.2

DISCLAIMER

This document was prepared as an account of work sponsored by the United States Government. While this document is believed to contain correct information, neither the United States Government nor any agency thereof, nor the Regents of the University of California, nor any of their employees, makes any warranty, express or implied, or assumes any legal responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by its trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof, or the Regents of the University of California. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof or the Regents of the University of California.

UCRL-1939
Unclassified-Physics Distribution

UNIVERSITY OF CALIFORNIA

Radiation Laboratory

Contract No. W-7405-eng-48

JUL 21 1960

PRODUCTION OF NEGATIVE μ MESONS AND THEIR BEHAVIOR IN NUCLEAR RESEARCH EMULSIONS

Dora F. Sherman

September 8, 1952

Berkeley, California

UCRL-1939
Unclassified-Physics Distribution

PRODUCTION OF NEGATIVE μ MESONS AND THEIR BEHAVIOR IN NUCLEAR RESEARCH EMULSIONS

Dora F. Sherman

Radiation Laboratory, Department of Physics
University of California, Berkeley, California

September 8, 1952

ABSTRACT

A beam of negative μ mesons produced inside the tank of the 184-inch cyclotron has been studied. 3 ± 1 percent formed one prong stars when stopped in Ilford C2 emulsion. Two two-prong stars with prong ranges of 2 or 3 microns were observed which appear to be fission-like disintegrations induced by μ^- capture. 32 percent of the μ^- mesons have clusters of grains about 1 micron in diameter or two pronglets about one micron long at their termini. These are interpreted as Auger electrons accompanying capture by a heavy nucleus, or in some cases as fission of the capturing nucleus. An upper limit on the cross section for direct production of negative μ mesons, $d\sigma/d\Omega dp$, in the forward direction at $pc = 129$ Mev, has been evaluated to be 0.015 times the cross section for production of negative π mesons in the same interval.

UCRL-1939
Unclassified-Physics Distribution

PRODUCTION OF NEGATIVE μ MESONS AND THEIR BEHAVIOR IN NUCLEAR RESEARCH EMULSIONS

Dora F. Sherman

Radiation Laboratory, Department of Physics
University of California, Berkeley, California

September 8, 1952

INTRODUCTION

Early studies[1] of the mesons coming directly from a cyclotron target bombarded by alpha particles revealed that some positive mesons coming from the target were muons but that negative muons, rather than coming from the target, came instead from regions where pions might decay in flight. The question of whether muons are also produced in a primary process in the target can be answered in the affirmative if such mesons can be detected in the presence of a background of muons arising from the decay of pions in the vicinity of the target.

When this experiment was undertaken, the only studies of the excitation produced by nuclear capture of muons had been carried out using cosmic ray muons, and it was of interest to verify these results using laboratory produced muons.

This paper reports an experiment[2] to study the production and behavior of negative muons using nuclear track emulsion detectors in the vicinity of a target inside the cyclotron. The bombarding proton beam had an energy of 340 Mev, which exceeds the threshold for single production of muons by more than 200 Mev, if such a process is possible, and also exceeds the threshold for production of muons in pairs, one member of which will have an energy of 60 Mev, and thus be capable of detection in this experiment.

EXPERIMENTAL APPARATUS

The target used was a rod of beryllium of cross section 1/4 in. x 1/4 in. Adjacent to this a channel was constructed which, when placed in the magnetic field, of the cyclotron, would admit particles from the target only if they emerged in the forward direction, i.e. parallel to the bombarding beam, in the momentum interval 129 $\pm$ 4 Mev/c. Particles originating from points other than the target would be admitted in a much wider momentum interval. Pions originating from the target and traversing the channel lie in the range interval 1.5 to 1.7 cm. of copper. In addition to these, a few higher energy pions will scatter into the channel and appear with longer ranges. Muons from the target, traversing the channel would appear in the range interval 2.0 to 2.85 cm. of copper. Muons which arise from decay of pions in flight will emerge from the channel distributed over a wider range interval. Since the density of pions rapidly decreases with distance from the target, the target region acts as a diffuse source of muons, even if all muons originate from decay of pions in flight.

Fig. 1 is a diagram of the experimental arrangement, showing the target, lead shielding, the channel, and the absorbers in which the photographic emulsion was embedded.

At the end of the channel, in the position marked A in Fig. 1 was placed a rectangular copper absorber, 2.0 cm. thick, which stops π mesons of momenta up to 142 Mev/c. However, μ mesons of momenta greater than 120 Mev/c penetrate this barrier because of their smaller mass. The μ mesons are then slowed down in a wedge shaped copper absorber and detected in a 200 micron Ilford C-2 emulsion placed behind the wedge. Immediately behind the emulsion an absorber of aluminum (chosen to reduce back scattering) was bolted,

so that the three absorbers formed a solid plate holder. Fig. 2 shows the position of the emulsion in the absorbers.

This method of stopping the π mesons was employed only after the experiment had been tried without using the rectangular absorber. Originally it was hoped to observe the π mesons and μ mesons on the same plate separated by range into two groups. One plate containing both the pions and muons admitted by the channel was scanned to obtain the muon-pion ratio used in estimating the upper limit on the cross section for direct production. However, without the rectangular block, some π mesons were able to reach the μ range portion of the plate by scattering into the glass backing the emulsion, or the cracks between the absorber and the emulsion, in which ranges are greater than in copper, so that when these mesons again scattered into the emulsion, they ended in the section of the plate containing the muon distribution. To eliminate this π contamination the rectangular absorber was placed in front of the detecting plate to stop the π mesons before there was any chance for them to enter media in the detecting system less dense than copper.

The entire apparatus was mounted on a cart which was moved through an air lock into the cyclotron tank, where the experiment was performed.

RESULTS

Following a 10 minute exposure, 369 ρ meson endings were observed. Their distribution in range is shown by the solid line histogram in Fig. 3. In addition to these a number of mesons were observed which formed stars. In line 1 of Table I these mesons are classified by the number of prongs in the stars they produce. In order to compare our star prong spectra with those of Adelman and Jones[3], Menon[4], and Adelman[5], the definition of a star prong

used by these experimenters has been adopted for this study. According to their definition, any track of length greater than one micron, and having a well defined direction of emergence from the star center is a prong.

Two sources of pion contamination are known. A few high energy pions scatter into the channel. Also, there appear to be pions produced in the shielding, probably by neutrons. This is indicated by the fact that of the six negative mesons which entered the emulsion at angles greater than 90° to the muon beam direction, only two were ρ mesons, while four formed stars. Also, one meson was found entering the emulsion at greater than 90° which underwent $\pi - \mu$ decay.

An attempt was made to distinguish between star forming muons and the pion contamination by grain counting all of the mesons which formed stars, and a sample of the non-star-forming mesons. Although groups of predominantly π mesons could be separated from groups of μ mesons by this method, the resolution was not sufficient to determine whether an individual meson was a pion or a muon.

Correction for the pion contamination was therefore carried out in the following manner: the number of mesons assumed to be pions in each section of the star prong spectrum was chosen to fit an Adelman distribution[5] as closely as possible, after assuming that all the mesons forming three or more prongs are pions. These mesons, (shown in line 3 of Table I) are subtracted from the observed distribution to deduce the star prong spectrum due to capture of muons. The results obtained are shown in line 4 of Table I. Of 372 μ^{-} mesons, 12 or 3 $\pm$ 1 percent formed one prong stars. No conclusive evidence for the formation of stars of more than one prong was found in this experiment, although two events were found in which a meson

ended in a two prong star, the prongs of which were only two or three microns long. These prongs are too heavily ionizing to be electrons and of too short range to be protons escaping the barrier of a still intact nucleus. They appear to be fission-like events. Although such stars are not a frequent consequence of π meson capture, the possibility that these may have been formed by π mesons cannot be excluded. Fig. 4 shows one of these stars. George and Evans[6], exposing plates underground to cosmic rays, deduced that 4.8 percent of the negative muons stopped formed one prong stars, and 0.6 percent formed small two prong stars.

Morinaga and Fry[7], studying negative muons from the Chicago cyclotron find about 3 percent forming stars with prongs greater than 20 microns. Of these, 88 percent are one prong stars, 8 percent are two prong stars, 2.7 percent are three prong stars and 1.3 percent are four prong stars.

A study of the endings of the ρ mesons under a magnification of 1375 X. showed that 32 percent of the non-star-forming mesons ended in spheroidal clusters of grains about one micron in diameter, or in two short pronglets, each about one micron long. Typical endings of this type are shown in Fig. 5. Such events were observed by Franzinetti[8], and were interpreted by Cosyns[9], et al. as due to internal conversion electrons resulting from capture of muons in silver and bromine. The fact that several experimenters[10] believe that some of these pronglets are too heavily ionizing to be electrons suggests as an alternate interpretation that some of these events too, are fission-like disintegrations. The study of these endings could better be made in a cloud chamber.

The energies of the mesons detected in the plate were measured by their ranges in the copper absorbers. The solid line histogram in Fig. 3 shows the observed range distribution of ρ mesons in the plate. The dashed line histo-

gram in the same figure is the range distribution of μ mesons which would be expected if the μ mesons were produced in the target. This curve was obtained from an observed range distribution of π mesons selected by the channel from a target of the same dimensions as the one used in this experiment. The ranges of μ mesons having the same momenta as the π mesons observed were computed and the relative abundances in each momentum interval of the spectrum plotted for these ranges.

An upper limit on the number of directly produced muons may be estimated by considering the observed distribution as the sum of the muons produced directly in the target, and the muons arising from decay in flight of pions near the target. The spectrum of these latter muons should be as if they originated from a wide, diffuse target centered at the real target. In particular, the distribution should not be double peaked, nor should its peak, if it has one, be displaced from the peak of a distribution from the real target. Keeping the decay-in-flight subject to these conditions, the maximum number of muons which could have come directly from the target was determined.

The resulting decay-in-flight spectrum is shown by the dotted line histogram in Fig. 3. The number of mesons between the dotted line and the solid line is the maximum number which can have been directly produced. This number may be compared with the number of π mesons produced in the same solid angle and momentum interval to obtain an upper limit on the ratio of the cross sections $d\sigma/d\Omega dp$ for muon and pion production. For this, a plate which had been exposed without the absorber A of Fig. 2 was scanned and the ratio of muons to pions admitted by the channel was found to be 0.13. Of the muons, 12 percent is the maximum fraction which could have been directly produced in the target. Therefore maximum value of $d\sigma/d\Omega dp$ at $pc \cong 129$ Mev, in the forward direction is 0.015 times the cross section for negative pion production in the same interval.

ACKNOWLEDGMENTS

Greatful thanks are due to Harry Heckman for construction of the channel and data on the π meson spectrum in the channel, to Mr. A. J. Oliver for the photographs of figures 4 and 5, to Dr. Walter Barkas for conceiving and proposing the experiment, and to Dr. Barkas and Dr. Frank Adelman for many helpful discussions throughout the course of the experiment.

TABLE I

Number of prongs	0	1	2	3	4	5	6
Observed Distribution	369	20	8	5	3	2	1
Adelman Distribution	27%	24%	24%	16%	8%		1%
Assumed numbers due to π contamination	9	8	8	5	3	2	1
Deduced μ Distribution	360	12	0	0	0	0	0
	96.8%	3%					

REFERENCES

1. John Burfening; Eugene Gardner; and C. M. G. Lattes: Phys. Rev., 75, 382, (1949)

2. Preliminary results of this experiment were reported to the Berkeley meeting of the Physical Society, in Dec., 1951. The abstract is published in the Phys. Rev., 85, 771, (1952).

3. F. L. Adelman, S. Jones: Science, 111, 226 (1950).

4. M. G. K. Menon, H. Muirhead, and O. Rochat: Phil. Mag. 41, 583 (1950)

5. F. L. Adelman, Phys. Rev. 85, 249 (1952), see also line 2 of Table I.

6. E. P. George and J. Evans: Proc. Phys. Soc. A, 64, 193 (1951)

7. H. Morinaga and W. F. Fry: Phys. Rev., 87, 182 (1952)

8. C. Franzinetti: Phil. Mag. 41, 86, (1950)

9. Cosyns, Dilworth, Occhialini, Schoenberg and Page: Proc. Phys. Soc. A, 62, 801 (1949)

10. Franzinetti, Loc. cit.
E. P. George, Private communication.

FIGURE CAPTIONS

Figure No.

1. Apparatus for producing a negative muon beam, showing the positions of the target, shielding, channel, and plate holder. During the bombardment the channel and chamber containing the plate holder were covered with additional shielding.

2. Absorber-emulsion configuration for detecting the negative muon beam.

3. Range histogram of ρ mesons. The solid line histogram is the observed distribution. The dashed line shows the computed distribution expected if all of the μ mesons are produced in the target. The dotted line histogram, obtained by subtracting the dashed line distribution from the solid line distribution, is the least possible number of mesons which could originate from decay in flight. The area between the dotted and the solid histograms represents the maximum number of mesons observed which could have been produced in a primary process in the target.

4. One of the small two prong stars, in which each prong is only 3 microns long.

5. Examples of muons ending in sheroidal clusters of grains or in one micron long pronglets.

Information Division
DB 9/9/52

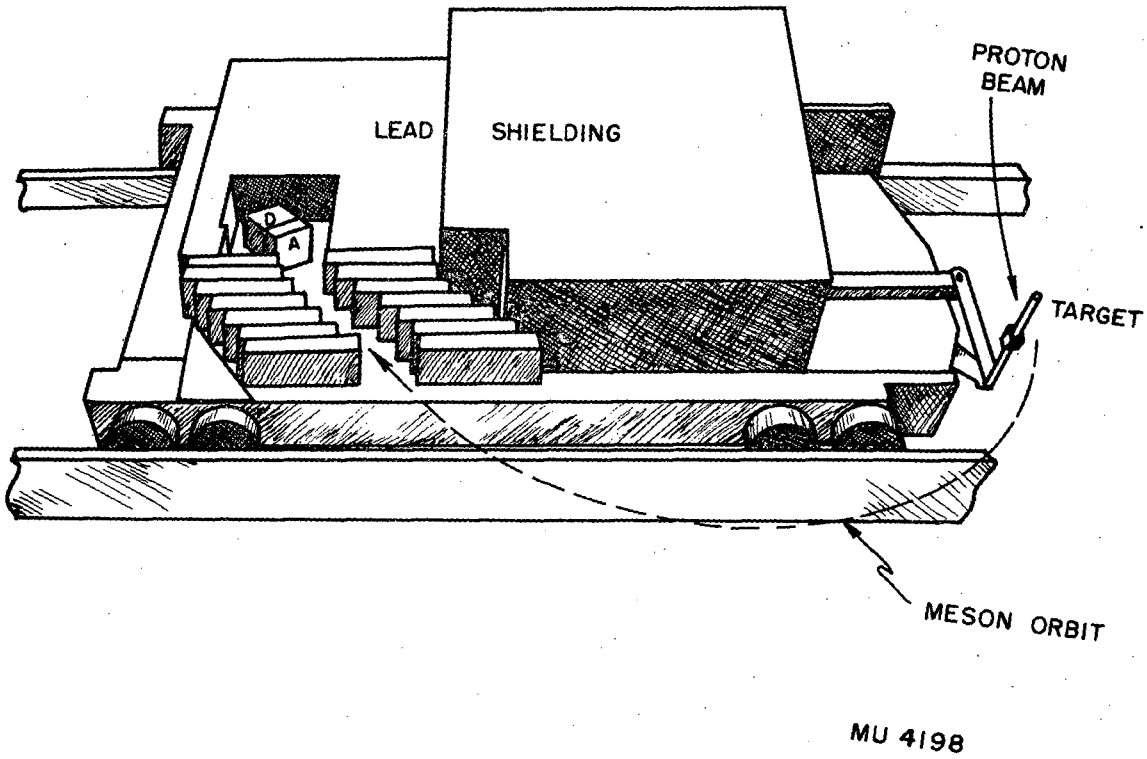


Fig. 1

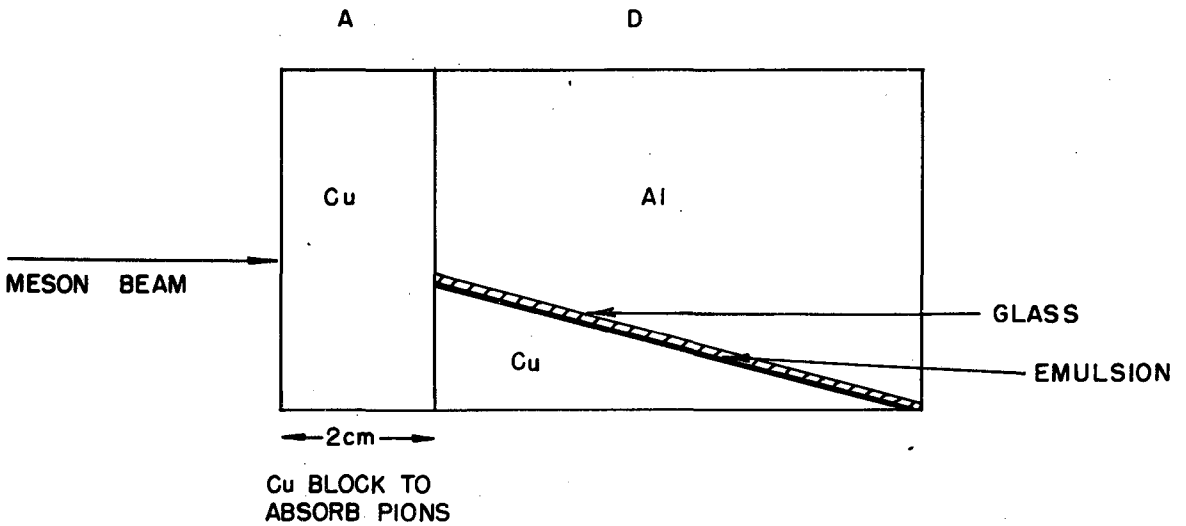
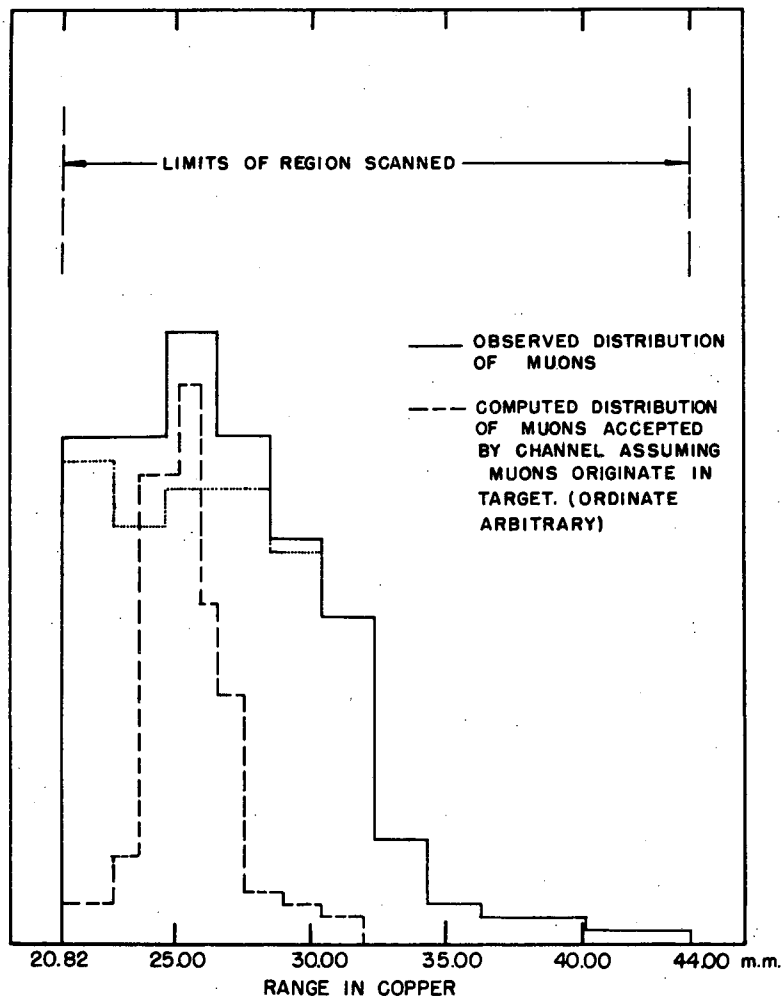

A
D
Cu
Al
MESON BEAM
GLASS
Cu
EMULSION
2cm
Cu BLOCK TO
ABSORB PIONS

FIG. 2

MU 4184



RANGE HISTOGRAM OF ρ MESONS

MU 4197

Fig. 3

Fig. 4

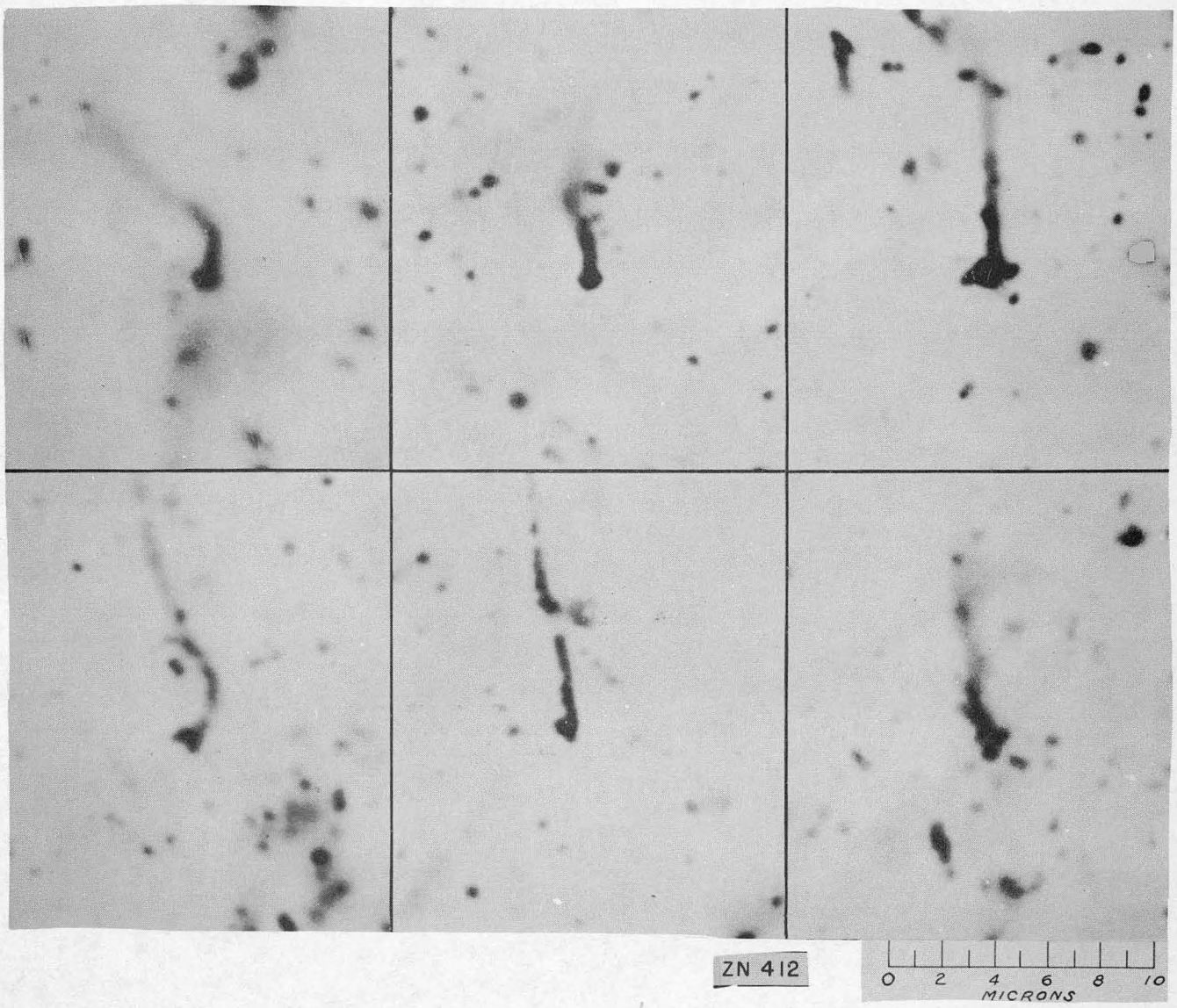


Fig. 5