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ABSTRACT

A spark chamber has been constructed of seven aluminum plates, each 1/2-in. thick and separated by a 1/4-in. gap. Using this device permits the trajectory of a charged particle to be observed by detecting the light produced by a spark discharge between the plates when a high-voltage pulse is applied to alternate plates. The efficiency of this chamber has been measured for high-energy charged particles produced at the Bevatron. When the chamber is filled with 1 atm of neon or argon, the efficiency per gap is greater than 99% if a 1/4-μsec pulse of greater than 10 kv for neon or 15 kv for argon is applied to the plates within 1/3 μsec after the charged particle traverses the gap between the plates. Multiple tracks, such as those produced by a nuclear reaction in the plates can easily be photographed. The recovery time of the chamber, after a spark discharge between the plates, is approximately 10 msec. The sensitive time is of the order of 10 μsec unless a clearing field is applied to one set of the plates. With a clearing field of approximately 160 v/cm, the sensitive time is reduced to less than 1/2 μsec. When the chamber had 4×10^5 particles incident on it in 0.1 sec, three tracks per trigger were sometimes observed, in agreement with the measured sensitive time. The chamber also functioned with a magnetic field of 13 kgauss parallel to the plates. The tracks were displaced by an amount proportional to the magnetic field. In addition, if a high clearing field, E, was applied and if a long time was allowed to

elapse before the high-voltage pulse was applied, the sparks in alternate gaps were displaced in opposite directions by an amount proportional to $E \times B$. Both the momentum and the time of traversal, relative to the time of applied voltage, could be determined in this manner.

PROPERTIES OF A SPARK CHAMBER*

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Certain kinds of experiments in high-energy physics could benefit from the use of a charged-particle detector with high spatial resolution combined with short time resolution. At present, the former characteristic is found in bubble chambers and photographic emulsions; the latter in scintillation and Čerenkov counters. A discharge chamber that has both of these properties has been described by Cranshaw and De Beer[1] and also by Fukui and Miyamoto.[2] This paper describes a similar device which has been tested in a beam of high-energy particles from the Bevatron.

The spark chamber is shown in Fig. 1; a block diagram of the electronics is shown in Fig. 2. A charged particle that passes through counter telescope $C_1C_2C_3$ also passes through the spark chamber in a direction approximately normal to the plates. The results reported here have been obtained with a chamber containing argon; the sensitive area was 6 by 6 in. A minimum-ionizing particle produces about 30 ion pairs in neon in each 1/4-in. gap. A coincidence in the counter telescope triggers an EFP60 discriminator circuit, which in turn triggers a 6130 hydrogen thyratron. This applies a 2-kv pulse to a 5949 thyratron, which in turn applies a pulse of up to 28 kv to alternate plates of the chamber. The

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rise time of this latter pulse is 25 mμsec. Within 0.1 μsec of the application of this pulse, a spark discharge occurs in each gap at the point where the particle passed. With the help of a mirror, 90-deg stereo photographs of the discharge were recorded on Tri-X film in a single camera. The aperture was f/11 with the camera 5 ft away. Some typical pictures are reproduced in Fig. 3. In order to obtain good time resolution, a constant clearing field was maintained between the plates; electrons from the traversal of off-time particles were thereby swept out.

The time resolution was measured by delaying the application of the high voltage to the plates. The minimum time between the passage of the particle and the arrival of the high-voltage pulse at the chamber was 0.3 μsec; most of this was due to the triggering delay of the thyratrons. Figure 4 shows the variation of efficiency of a single gap in argon as a function of additional delay for various clearing fields. The curves show that it is possible to achieve a resolution time of 0.5 μsec with an efficiency better than 99%. The efficiency for sparks to appear in all six gaps was always approximately the sixth power of the efficiency of a single gap, showing that the gaps behaved independently. Similar curves are obtained when the chamber is filled with neon or helium.

The curves of Fig. 4 were obtained with the clearing field in the opposite direction to the pulsed field. With the clearing field in this direction, the electrons--which initiate the discharge--are swept towards one plate. There is then sufficient room for development of spark breakdown in an electron avalanche moving towards the other plate. With a clearing field of the same magnitude in the other direction, high efficiency was not possible because of the nonzero distance required for the development of a spark.[3] This distance decreases with increasing amplitude of the high-voltage pulse; when the voltage is low enough for the breakdown distance to be comparable with the gap width, the efficiency is reduced. This effect is shown in Fig. 5.

The recovery time of the chamber was measured by triggering the chamber with two particles occurring a fixed time apart. The results are summarized in Fig. 6. These curves were not controlled by the recovery of the high-voltage supply; at 4 msec delay, the high voltage had recovered to a level at which the efficiency is 60%.

An attempt was made to find a clearing field that would give a low efficiency for particles with minimum ionization and high efficiency for densely ionizing particles. With a clearing field of 47 v. and a delay of 0.6 μsec in neon, the efficiency was 60% for minimum ionization and 80% for three-times-minimum ionization.

With all parameters held fixed, it was found that the resolving time of the chamber increased during a period of several days after evacuating and refilling the chamber. Most of the change occurred in the first few hours after the chamber was filled. This effect was presumably due to the change in concentration of some impurity. The resolving time was restored to the initial value by an increase in the clearing field. Addition of 1/2% oxygen or 5% carbon dioxide did not affect the efficiency appreciably. Greater quantities did reduce the efficiency, presumably by reducing the probability that an electron would survive until the high-voltage pulse was applied. These added impurities did not affect the recovery time. Addition of a small amount (~ 1/5%) of argon to neon did not have any marked affect on the brightness of the spark, nor on the time resolution. In the 1/4-in. gap, no tendency was seen for the spark in a single gap to follow the track of the particle for tracks at angles up to 45 deg to the normal to the plates; with angles greater than this, multiple sparks occurred. One of the picutres in Fig. 3 shows the appearance of such a track. In tests with a 1/2-in. gap some sparks did partially follow the particles in the same way as shown in the results of Fukui and Miyamoto,[2] but the effect did not appear consistently.

The estimate of the resolving time obtained as described above was confirmed by tests in a beam of 4×10^6 particles per sec; approximately three tracks per trigger were observed in the chamber. This result, together with observation of interaction events in the plates leading to secondary particles, shows that there is no loss of efficiency when several particles are detected at once.

When the chamber was placed in a magnetic field perpendicular to the particle trajectory, the sparks in alternate gaps were displaced in opposite directions as in Fig. 7. The direction of displacement was $-\mathbf{E} \times \mathbf{B}$, with $\mathbf{E}$ the clearing field. This is due to the familiar cycloidal motion of the electrons in the crossed fields, modified by the presence of the gas. This situation is similar to that used by Townsend in his measurements of ionic mobilities.[4] With a clearing field of 80 v/cm, a delay of 1 μsec, and a magnetic field of 13 kgauss, the relative displacement in successive gaps was about 1 cm. This displacement is proportional to the lapse of time between passage of the particle and application of the high voltage. It is conceivable that this effect could be used to reject accidental particles; an out-of-time track would have an incorrect displacement. The time resolution might be made as short as 0.1 μsec in this way. The efficiency of the chamber was still greater than 99% in a magnetic field of 17.5 kgauss.

Gases of ordinary purity were used; welder's argon, for example, was found to be quite satisfactory. For this reason values of electron mobilities that can be deduced from this work should not necessarily agree with published values. It is well-known that minute quantities of impurities have drastic effects on mobilities.[5]

It is concluded that it is possible to construct a spark chamber which has much better spatial resolution than any practical counter array and a time resolution of less than 0.5 μsec. Its use could greatly simplify an experiment in which accurate observation of a rare event in an intense flux of particles is required.

It is a pleasure to thank Professor James Cronin of Princeton University for many helpful discussions.

References

1. T. E. Cranshaw and J. F. De Beer, Nuovo cimento 5, 1107 (1957).

2. S. Fukui and S. Miyamoto, Nuovo cimento 10, 113 (1959).

3. J. M. Meek and J. D. Craggs, Electrical Breakdown in Gases (Clarendon Press, Oxford, England, 1953).

4. J. Townsend, Electrons in Gases, (Hutchinson and Co., Ltd., New York, N. Y. 1947), p. 20.

5. See for example J. C. Bowe, Phys. Rev. 117, 1411 (1960).

Figure Legends

Fig. 1. Diagram of the spark chamber.

Fig. 2. Block diagram of electronics. Hydrogen thyratrons 1 and 2 are Kuthe type 6130 and 5949, respectively.

Fig. 3. Typical photographs obtained with the spark chamber.

(a) Two particles passing through the chamber. One has interacted in a plate. Minimum ionizing particles enter from the left.

(b) Two particles passing through the chamber obliquely, one at 36 deg, the other at 25 deg to the normal to the plates.

Fig. 4. Efficiency of a single 1/4-in. gap in 1 atm of argon as a function of delay in application of the high-voltage pulse. The zero of the delay axis is the time at which the particle passed through the chamber.

Fig. 5. Efficiency of a single 1/4-in. gap in 1 atm of neon and argon as a function of pulse voltage.

Fig. 6. Efficiency for a single gap to spark on a second particle as a function of the time between particles. The clearing field was -40 v/cm.

Fig. 7. Effect of a magnetic field of 13-kgauss with a clearing field of 80 v/cm and a time delay of 1 μsec. The gas was argon.

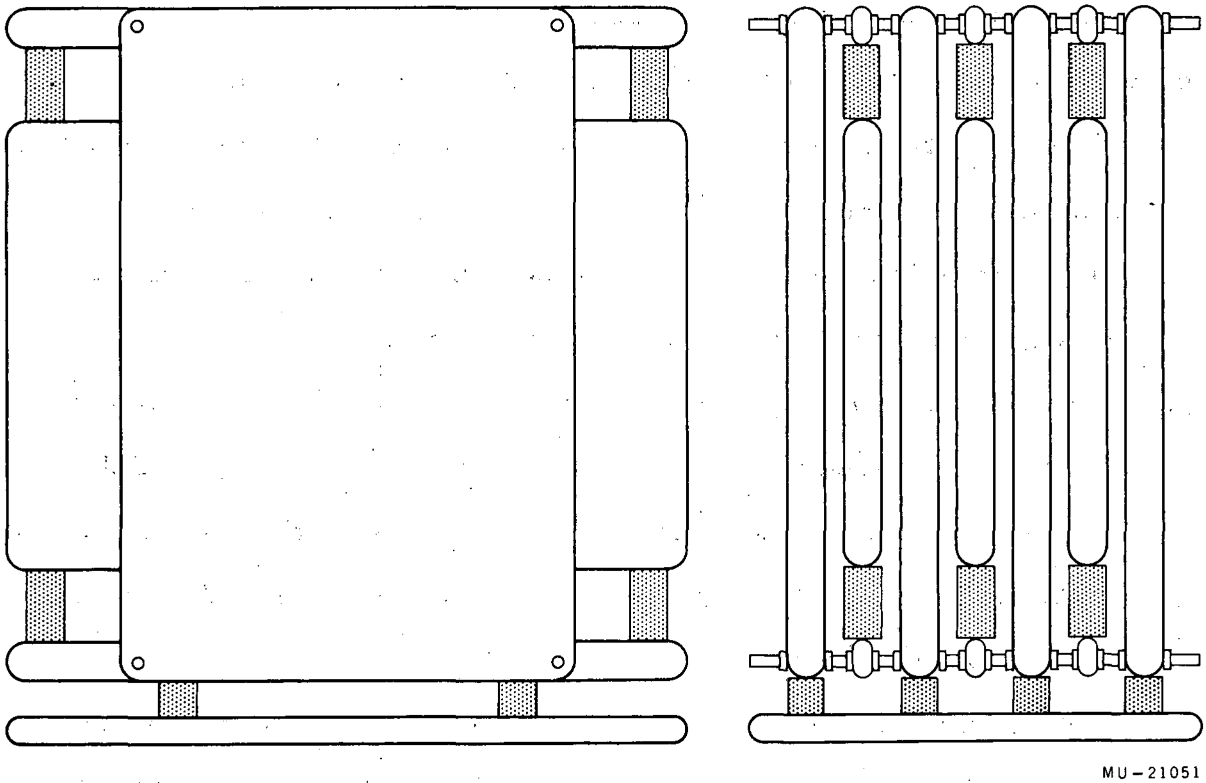


Fig. 1.

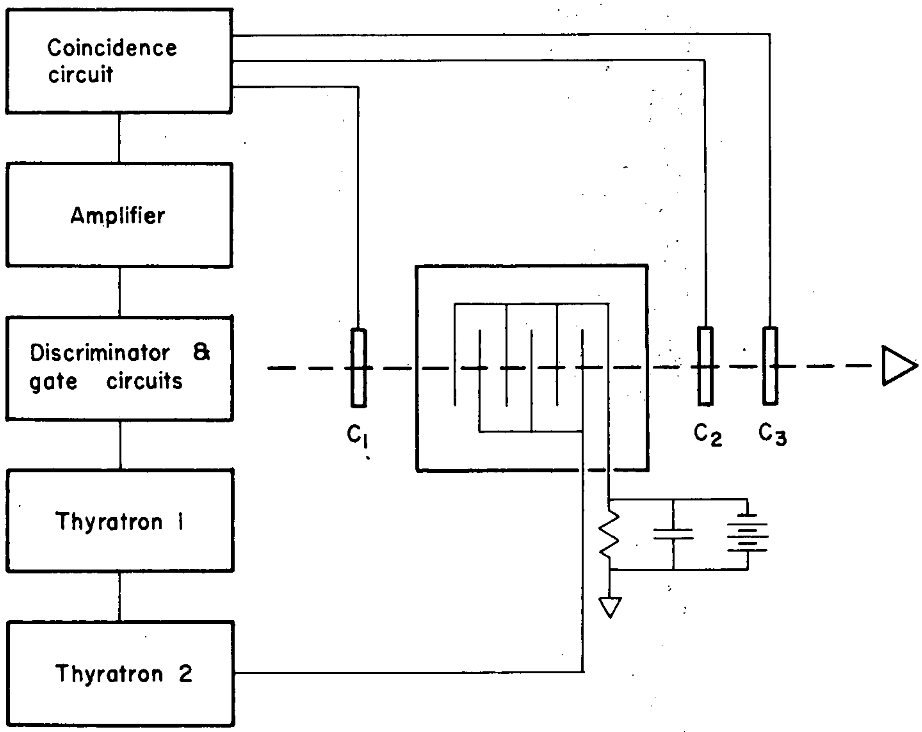
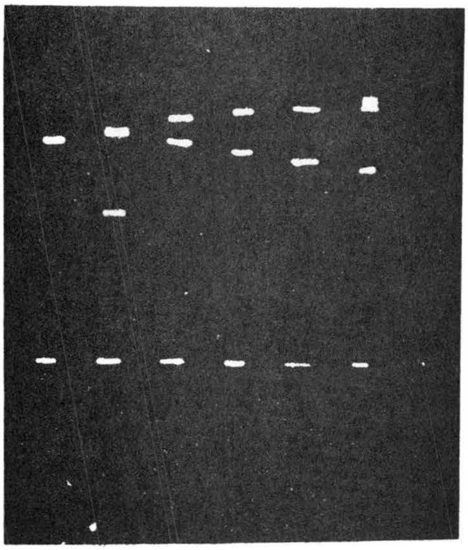
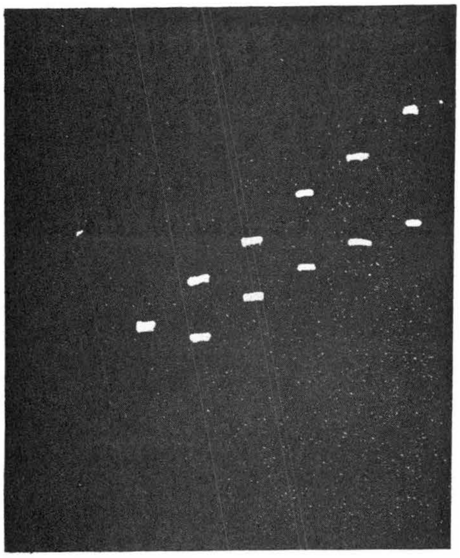

Coincidence circuit
Amplifier
Discriminator & gate circuits
Thyratron 1
Thyratron 2
C1
C2
C3
MU-21052

Fig. 2.



(a)



(b)

ZN-2565

Fig. 3.

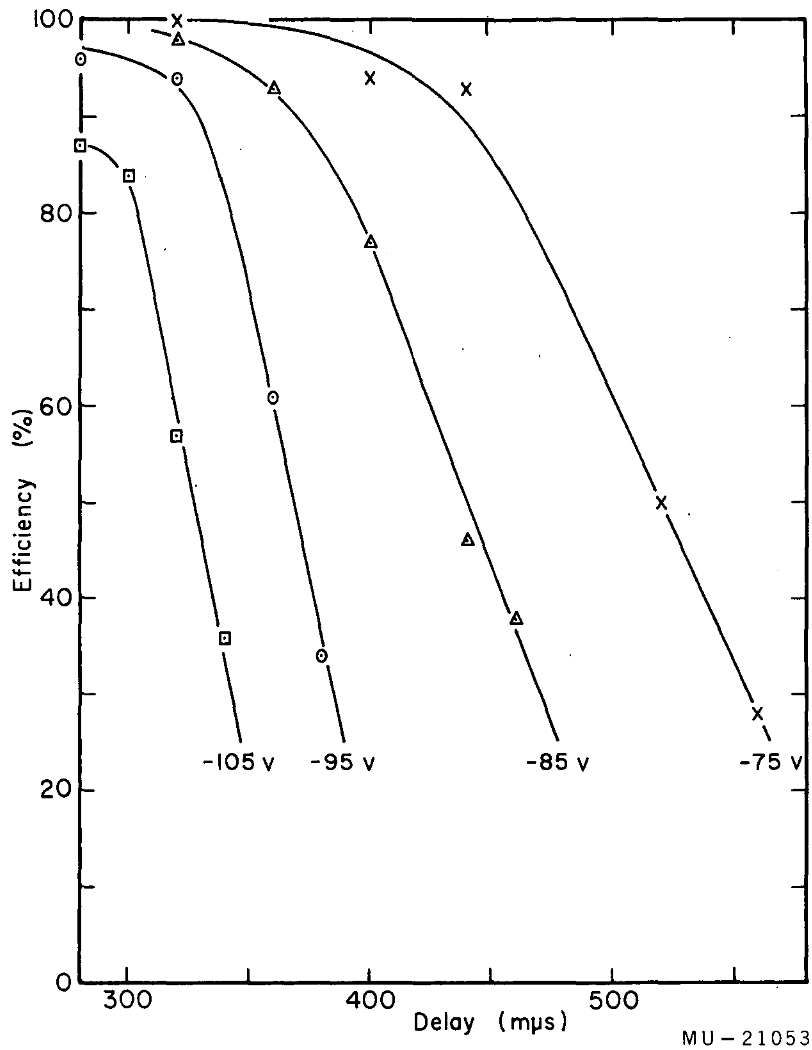

100
80
60
40
20
0
Efficiency (%)
300
400
500
Delay (mμs)
-105 v
-95 v
-85 v
-75 v
MU-21053

Fig. 4.

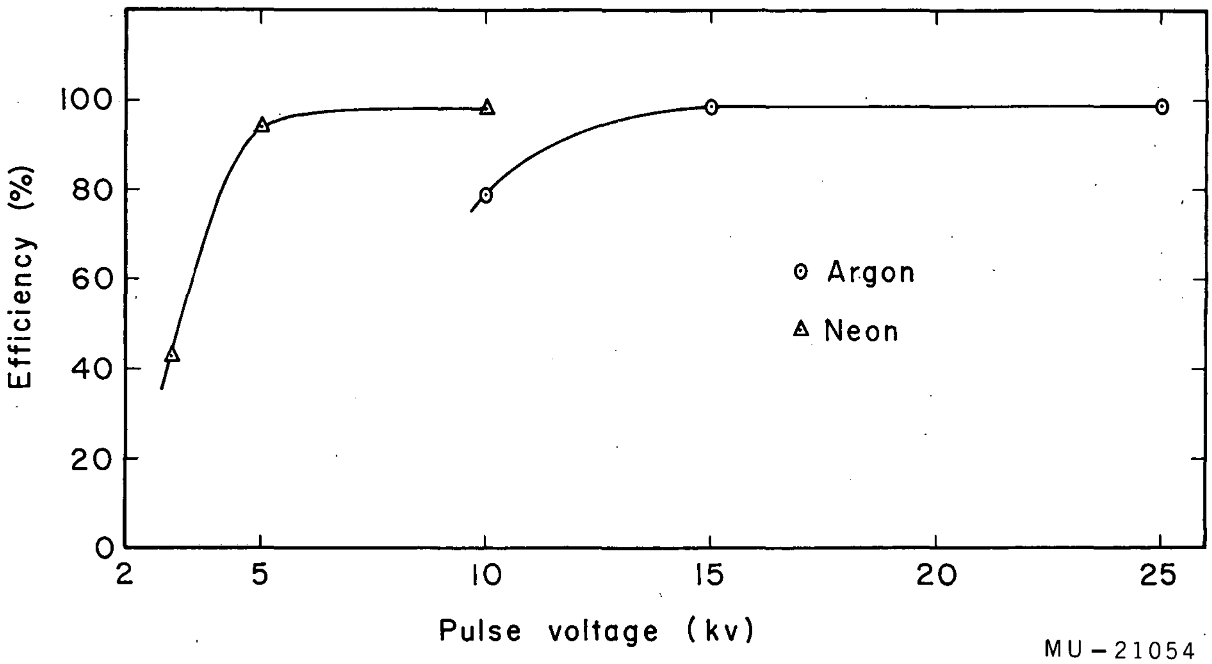

Efficiency (%)
0
20
40
60
80
100
2
5
10
15
20
25
Pulse voltage (kv)
Argon
Neon
MU-21054

Fig. 5.

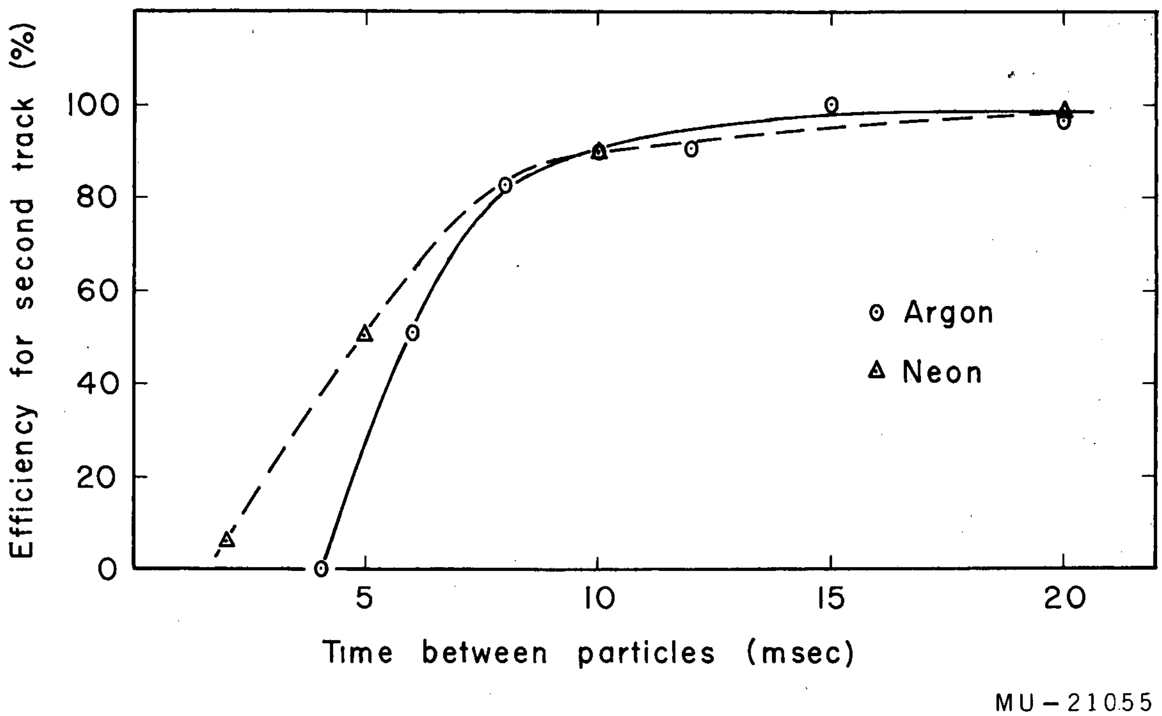
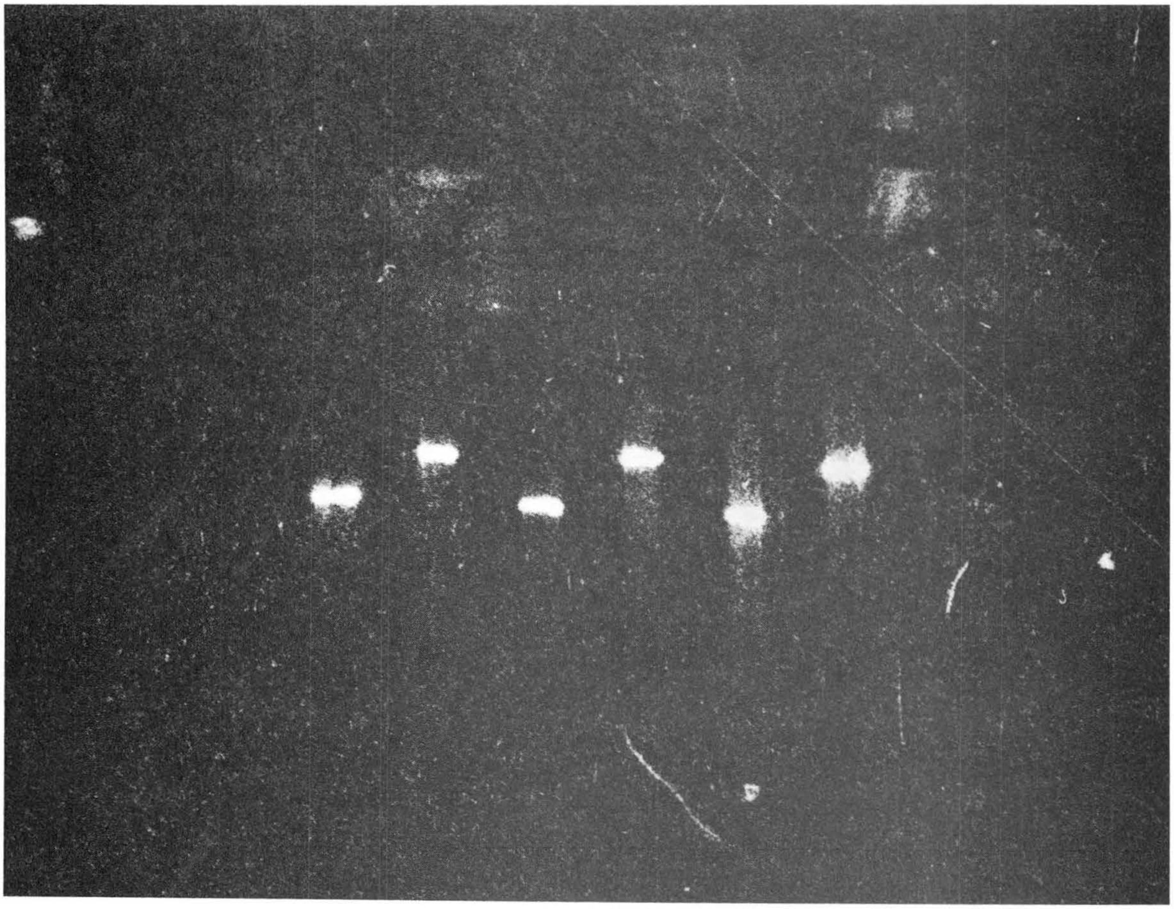

Efficiency for second track (%)
100
80
60
40
20
0
5
10
15
20
Time between particles (msec)
Argon
Neon
MU-21055

Fig. 6.



ZN-2566

Fig. 7.