# Čerenkov Radiation Detector for the Selection of Slow Particles*

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A cloud chamber in a magnetic field has been operated at an altitude of 1750 m. The chamber was triggered by a slow-particle selector which utilizes the properties of the Čerenkov radiation. An analysis of 1142 pictures is presented and one possible example of the nuclear capture of a $K^-$ particle is discussed in detail.

SEVERAL authors[1,2] have described slow-particle selectors using a Čerenkov radiation detector as a means of imposing a restriction on the velocity of the particles traversing their apparatus. A device very similar to that described by Hyams[1] is shown in Fig. 1 and has been operated at Mt. Wilson (1750 m) for several months. In principle the cloud chamber is triggered by charged particles which trip the Geiger counters $A$, $B$, and $C$ without emitting any Čerenkov radiation on traversing the Lucite block. This last restriction is obtained by using the amplified output pulses of the photomultiplier tube (RCA 5819) in anticoincidence with the Geiger counters. Because Čerenkov radiation is emitted only by particles traveling faster than the critical velocity for the dielectric material they traverse, fast particles will not trip the chamber. This critical velocity is $\beta\sim 0.66$ for Lucite.

The cloud chamber was operated in an average magnetic field of 3500 gauss and was held at constant temperature ($\pm 0.1$°C) by a surrounding thermostatted heat shield. All momentum and angle measurements were made and corrected in the manner described by Leighton *et al.*[3] A brief study of no-field curvatures of tracks in the chamber indicated that a reasonable value of the maximum detectable momentum for a 12-cm track in the chamber is 1.5 Bev/$c$. Table I gives an analysis of the 1142 pictures obtained during the total period of operation. The pictures were taken at a rate of 2.5 hr$^{-1}$. It is clear from the table that the Čerenkov detector allows a large number of fast particles to trigger the apparatus, but this is not surprising in view of the relatively poor light collection efficiency of the photomultiplier tube for the total volume of the Lucite block. The initial identification of particles was obtained either from momentum measurements and a visual estimate of the ionization or from the loss in momentum suffered by a particle traversing the $\frac{1}{2}$-in. copper plate mounted in the center of the chamber. No pictures which could be interpreted as the decay in flight of an unstable particle were obtained.

TABLE I. An analysis of 1142 pictures triggered by the Čerenkov selector.

| Type of event | Number |
|---|---|
| Single slow particles: | |
| Possible $K$ particle | 1 |
| Protons | 38 |
| Mesons | 51 |
| Undetermined | 10 |
| Single fast particles: | 519 |
| Multiple events: | |
| Electron showers | 146 |
| Penetrating showers | 8 |
| Blanks | 298 |
| Slow electrons from top of chamber | 71 |
| Total | 1142 |

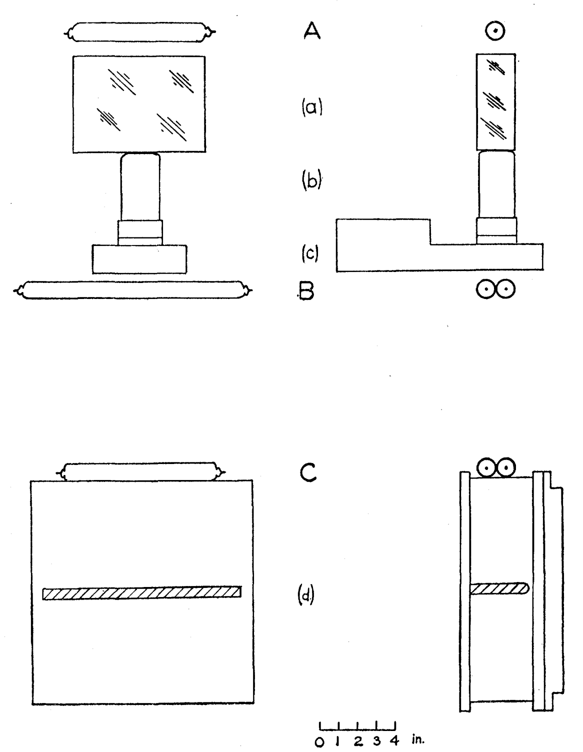


FIG. 1. Diagram of the apparatus. $A$, $B$, and $C$ are Geiger counters; (a) is a Lucite block, (b) an RCA 5819 photomultiplier tube, (c) a preamplifier, and (d) the cloud chamber containing a $\frac{1}{2}$-in. copper plate. A 2-in. layer of lead bricks mounted 18 in. above counter $A$, the mu metal and iron magnetic shields surrounding the photomultiplier (b), and the magnet yoke are not included in the figure.

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[1] T. Duerden and B. Hyams, Phil. Mag. 43, 717 (1952); B. Hyams, Bagneres Conference Report, (unpublished, 1953).
[2] J. Keuffel and L. Mezzetti, Phys. Rev. 94, 797(A) (1954).
[3] Leighton, Wanlass, and Anderson, Phys. Rev. 89, 148 (1953).

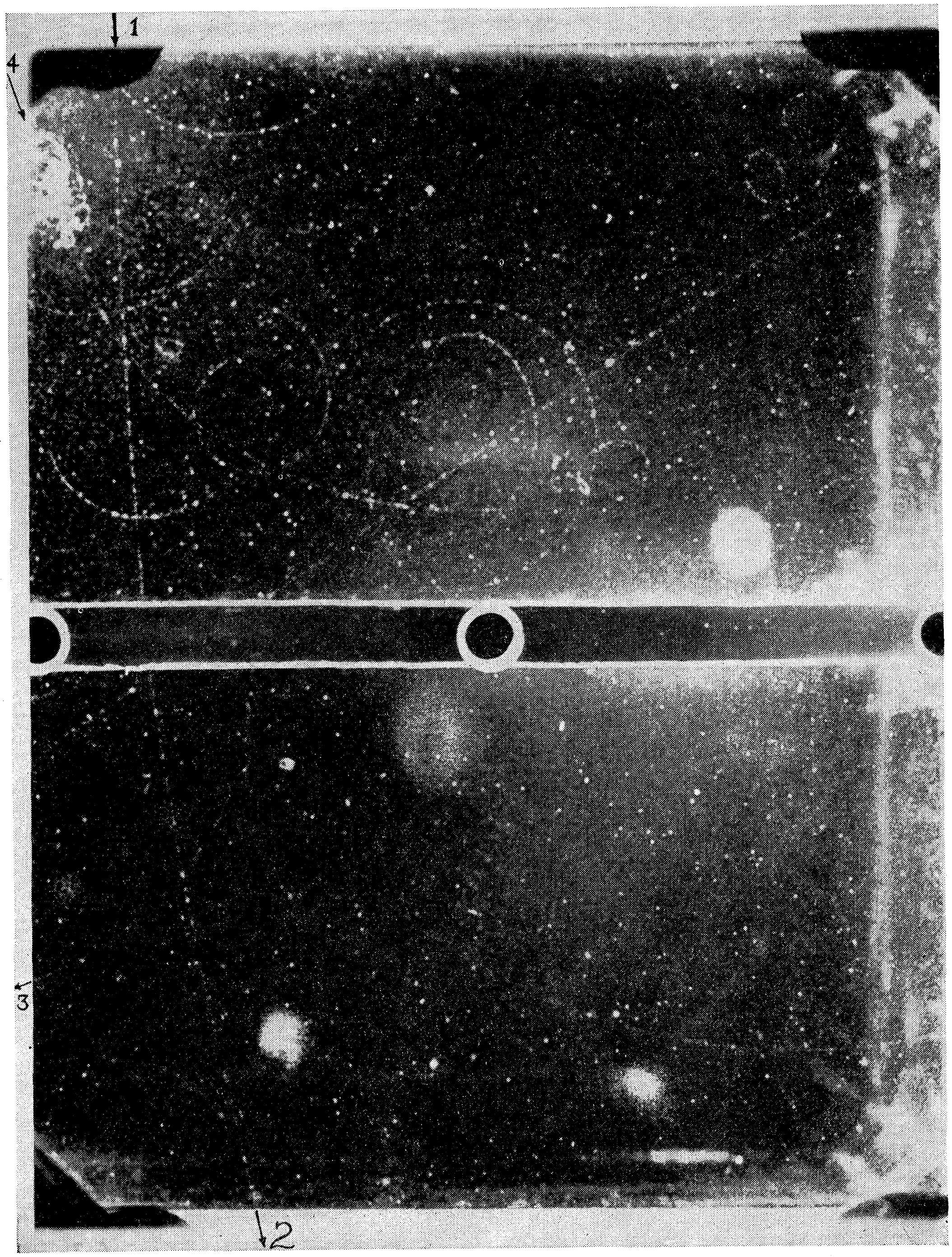


Fig. 2. Photograph of a negative particle, 1, entering the upper left-hand side of the chamber and giving rise to track 2 below the plate. Tracks 3 and 4 are electron tracks in the plane of the chamber used for comparison in the ionization estimates. (All of the other electrons are moving steeply forward or backward in the chamber.)

One event in which a negative particle apparently traverses the copper plate proved to be of considerable interest and is shown in Fig. 2. The measurements are: $P_1 = 230 \pm 37$ Mev/$c$, $I_1 = 5(\pm 1) \times I_{\text{min}}$; $P_2 = 116 \pm 12$ Mev/$c$, $I_2 = 3(\pm 1) \times I_{\text{min}}$; $P_3 = 9.3$ Mev/$c$; and $P_4 = 11$ Mev/$c$. The angle between tracks 1 and 2 is $5^\circ \pm 2^\circ$. Tracks 3 and 4 are assumed to be electrons and have had their density on the film compared to that of tracks 1 and 2 by a photometric method to give the ionization values, $I_1$ and $I_2$ quoted above. Although this photometric method has not yet been developed in complete detail, it is considered to be less subjective

than the usual visual estimates and hence has been used in the analysis. If one accepts these values of the ionization, the masses of the particles are: $M_1$: 840–1440 $m_e$ and $M_2$: 250–520 $m_e$ where the range of values results from the combined uncertainty in the momenta and ionizations. The simplest explanation of this event is that a $K^-$ particle comes to rest in the plate and causes the ejection of a light meson. If the $K^-$ is assumed to have a mass of $\sim$1000 $m_e$, it should come to rest very near the center of the copper plate, and a light meson ($\pi$ or $\mu$) would lose about 15 Mev/$c$ before emerging from the plate with a momentum of 116 Mev/$c$. Thus this event can be interpreted either as a $K^-$-produced star which ejects a $\pi$ meson of 51-Mev kinetic energy or as a $K^-$ decay at rest with the emission of a light meson. The former possibility seems to be more likely because the stopping material has a high atomic number and similar events have been reported elsewhere.[4] However, it should be emphasized that both of these interpretations hinge on the ionization determinations. If ionization is ignored, the momentum change implies either that a particle of mass $\sim$600 $m_e$ traversed the plate or that a lighter particle ($\pi$ meson or electron) suffered an anomalously large momentum loss on traversal. The possibility that this event represents a positive $\pi$ meson which goes upward and gives rise to a proton which in turn emerges from the plate in an upward direction is energetically acceptable, but considered highly unlikely in view of the ionization of track 1 and the geometry of the experiment. Thus the simplest and most consistent explanation of this event seems to be that a $K^-$ particle stops in the plate and ejects a $\pi^-$ meson from a nuclear interaction.

The author would like to express his thanks to Dr. R. B. Leighton who constructed the magnet and cloud chamber and to Mr. E. K. Bjørnerud for performing the ionization measurements referred to above. He would also like to express his appreciation to Professor C. D. Anderson for many stimulating and enlightening discussions.

[4] Lal, Pal, and Peters, Phys. Rev. **92**, 438 (1953); Hill, Salant, and Widgoff, Phys. Rev. **94**, 1794 (1954); Major, Macpherson, Parkash, and Rochester (private communication).

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# Nuclear Fine Structure in the $\mu$-Mesonic Atom*

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The $2p-1s$ transition of a $\mu$-mesonic atom is split not only by the spin-orbit energy but also by the electric quadrupole interaction between meson and nucleus. If a high-$Z$ nucleus has excited states at several hundred kilovolts or less this interaction can be expected to mix nuclear states, so that for example an even-even nucleus with ground state spin zero can produce a quadrupole fine structure. General formulas are given for the calculation of the line patterns; these are worked out for W, $U^{238}$, and $Ta^{181}$. The resulting fine structure is spread over a region of 300–500 kev. The details of the positions and intensities of the lines depend on the quadrupole moments of the excited nuclear states as well as on other parameters which can in principle be measured in other types of experiments; the effect therefore offers a method for investigating these excited moments. A certain fraction of the mesonic gamma rays can be followed by a nuclear radiation; this fraction can be as high as 0.50.

## I. INTRODUCTION

The $\mu$-mesonic atom has proved to be a useful tool in the measurement of nuclear size.[1,2] The reasons for its utility as a probe for nuclear electromagnetic effects are well summarized by Wheeler,[3] who emphasizes the smallness of the Bohr orbits and the transparency of nuclear matter to $\mu$ mesons.

Atomic electrons are also commonly used as a tool in nuclear physics, the fine structure of their spectrum yielding values of magnetic dipole and electric quadrupole moments for the ground states of nuclei. There are certain striking differences, however, between an electronic- and a $\mu$-mesonic atom which enable the spectrum of the latter to yield additional nuclear information. The most important of these, for our purposes, concerns the relative fineness of the atomic and nuclear level spacings. (All qualitative arguments in the following shall be made for nuclei at the heavy end of the periodic table.) The difference between the energies of a $2p$ and $1s$ $\mu$ meson is several Mev; if now the nucleus in question has low-lying levels with spacings $\sim$100 kev, the meson sees the nucleus not as a rigid structure in its ground state, but as a system in an almost degenerate mixture of several states. A fine structure is induced in the $\mu$ levels which depends on the nondiagonal as well

* A preliminary report on this work was given at the May, 1954 Washington meeting of the Americal Physical Society [Phys. Rev. **95**, 654 (1954)]. It has subsequently been called to the author's attention that a paper on the same subject by L. Wilets is to be published.
[1] V. L. Fitch and J. Rainwater, Phys. Rev. **92**, 789 (1953).
[2] L. N. Cooper and E. M. Henley, Phys. Rev. **92**, 801 (1953).
[3] J. A. Wheeler, Phys. Rev. **92**, 812 (1953).

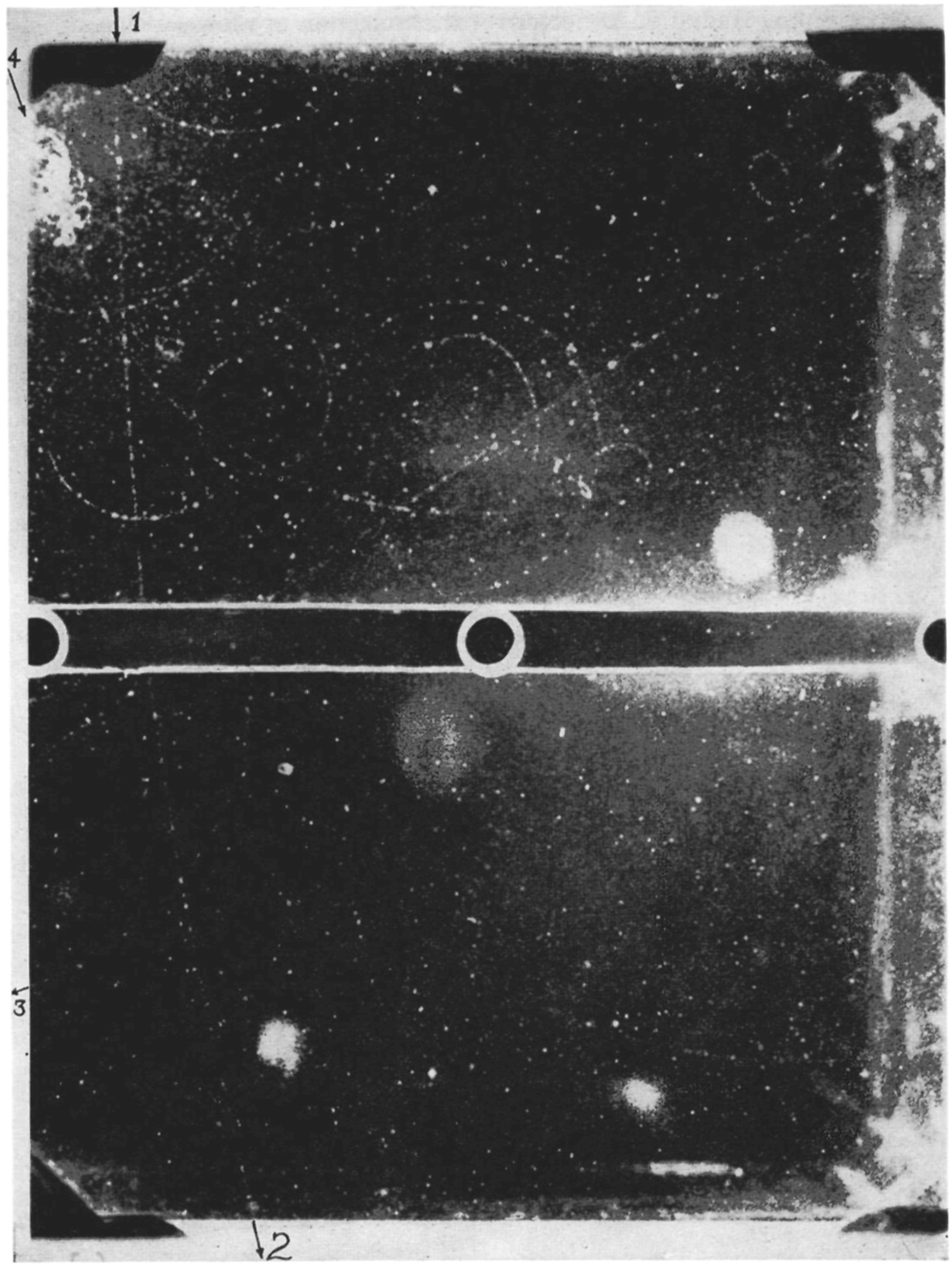


FIG. 2. Photograph of a negative particle, 1, entering the upper left-hand side of the chamber and giving rise to track 2 below the plate. Tracks 3 and 4 are electron tracks in the plane of the chamber used for comparison in the ionization estimates. (All of the other electrons are moving steeply forward or backward in the chamber.)