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Authors

Perez-Mendez, Victor.

Atkinson, John H.

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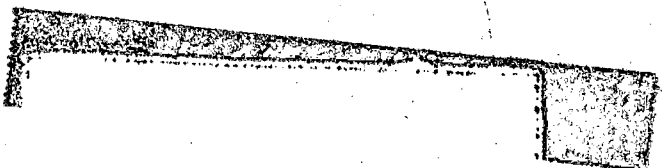
GAS CHERENKOV COUNTERS

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GAS CHERENKOV COUNTERS

Victor Perez-Mendez and John H. Atkinson

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Victor Perez-Mendez and John H. Atkinson

Lawrence Radiation Laboratory
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ABSTRACT

A gas Cherenkov counter is described which is suitable for charged-particle detection in the Bev region (β from 0.980 to 0.999). Calibrations of the counting efficiency are included along with a table of indices of refraction of suitable gases. The use of this counter as a threshold detector to discriminate between elastic and inelastic pions in the momentum range of 1 to 2 Bev/c is discussed.

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I. INTRODUCTION

The Cherenkov effect has been used increasingly during the past few years as a means of detecting and identifying high-energy particles. Many types of counters have been constructed to serve various purposes such as the identification of particles of mass m_1 from a flux of particles of mass m_2 which have the same momentum. From the theory of Frank and Tamm,¹ the Cherenkov radiation is confined to a narrow conical shell about the direction of the incoming particle with the opening angle θ of the cone given by $\cos \theta = 1/n\beta$. Also, the number of light quanta with frequencies between ν and $(\nu + d\nu)$ per unit length of path of the particle with charge e is given by

$$N(\nu) d\nu = 4\pi^2 \frac{e^2}{hc^2} \left(1 - \frac{1}{n^2\beta^2}\right) d\nu, \quad (1)$$

where n is the index of refraction. For a singly charged particle integrated from 3500 to 5600 Å (the spectral response of the S11 photocathode) we have

$$N = 490 \left(1 - \frac{1}{n^2\beta^2}\right), \quad (2)$$

where N is the number of quanta per centimeter of path length. The velocity selection may be accomplished either by detecting the Cherenkov light within a given angular range, or by using the threshold properties of the Cherenkov effect, i. e., $\beta = \frac{1}{n}$.

In practice the correlation between β and the angle of the Cherenkov light can be used in a velocity-selecting device for particles with values of β less than 0.99 where the differential change in β corresponds to a physically usable angular interval.² However, for higher-energy particles with values of β greater than 0.990, the change in angle versus β is too small to be readily useful, and hence it is more practical to use the threshold properties of the Cherenkov effect in this energy region.

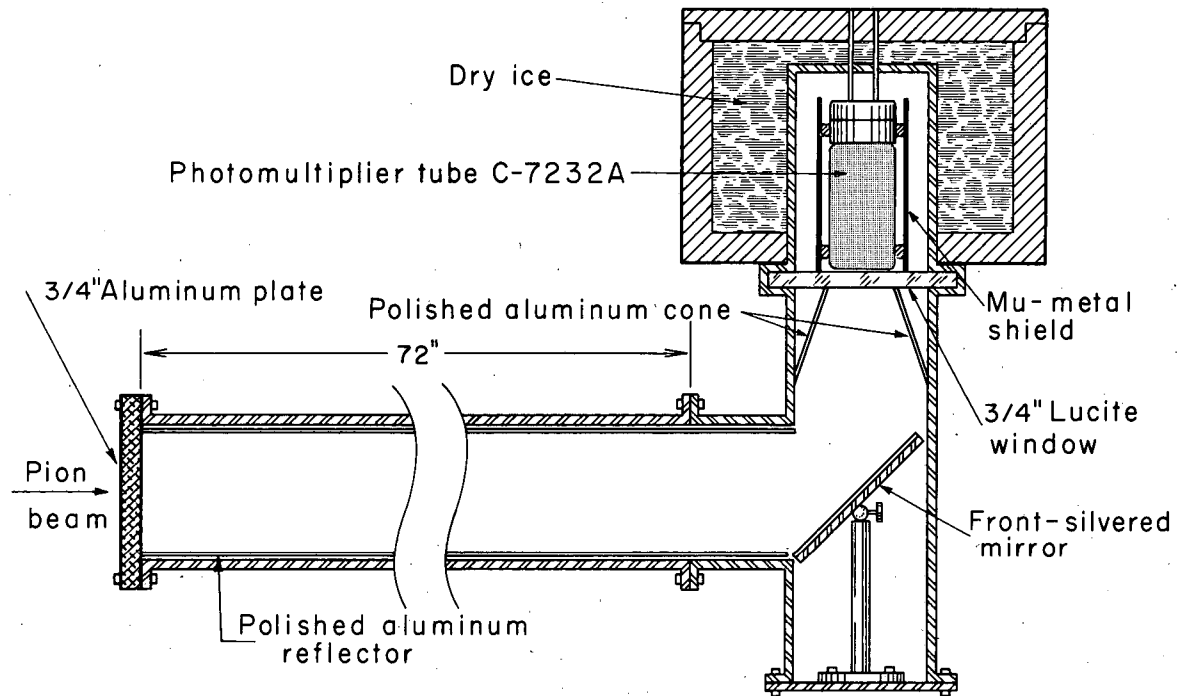
This report describes the construction and performance of a Cherenkov counter for the detection of particles with values of β ranging from 0.980 to 0.999. The corresponding values of index of refraction for the threshold of the Cherenkov effect range from 1.0204 to 1.00100, which necessitates the use of a radiator in the gaseous phase.

II. DESCRIPTION OF COUNTER

The counter assembly is shown in Fig. 1. The gas radiator is contained in the cylindrical steel shell which is 6ft long and 4 in. in diameter. The inner surface of the cylinder is made reflecting by having a thin shell of polished aluminum rolled into it. Standard 4-in. pipe flanges are used throughout to simplify the construction. The Cherenkov light is deflected from the beam at the rear of the radiating cylinder by a 45° plane, front-aluminized mirror. This mirror reflects the light up 90° through a Lucite window onto a photomultiplier tube. The window (3/4-in. thick) makes a pressure seal to the gas container and can be used up to pressures of 150 lbs/in.². The small aluminum cone in front of the Lucite window has a polished inner surface and serves to collect the light produced by particles that traverse the radiator cylinder slightly off-axis.

The photomultiplier tube is a 16-stage RCA C7232A tube and has its cathode window in optical contact with the Lucite window via a thin layer of silicone grease. Adequate magnetic shielding for operation around the Bevatron is provided by a 1/16-in. mu metal shield and the 1/4-in. iron walls of the multiplier housing.

In order to decrease the number of noise pulses, the photomultiplier is maintained at dry-ice temperature by enclosing its housing in a Styro-foam box filled with dry ice. The photomultiplier housing has then to be airtight to prevent moisture from condensing inside the socket assembly. Also, the gas in the counter must be very dry to prevent frost, which obscures the optical path, from forming on the Lucite window. Silica gel bags packed in the counter under the turning mirror and silica gel refrigeration dryers in the filling lines accomplish this satisfactorily.



MU-16403

Fig. 1. Cross-sectional view of gas Cherenkov counter.

III. PERFORMANCE

The detection efficiency of this counter for counting particles was investigated experimentally using a monochromatic beam of pions from the Bevatron with a momentum of 3.0 ± 0.1 Bev/c ($\beta \approx 0.9989$).

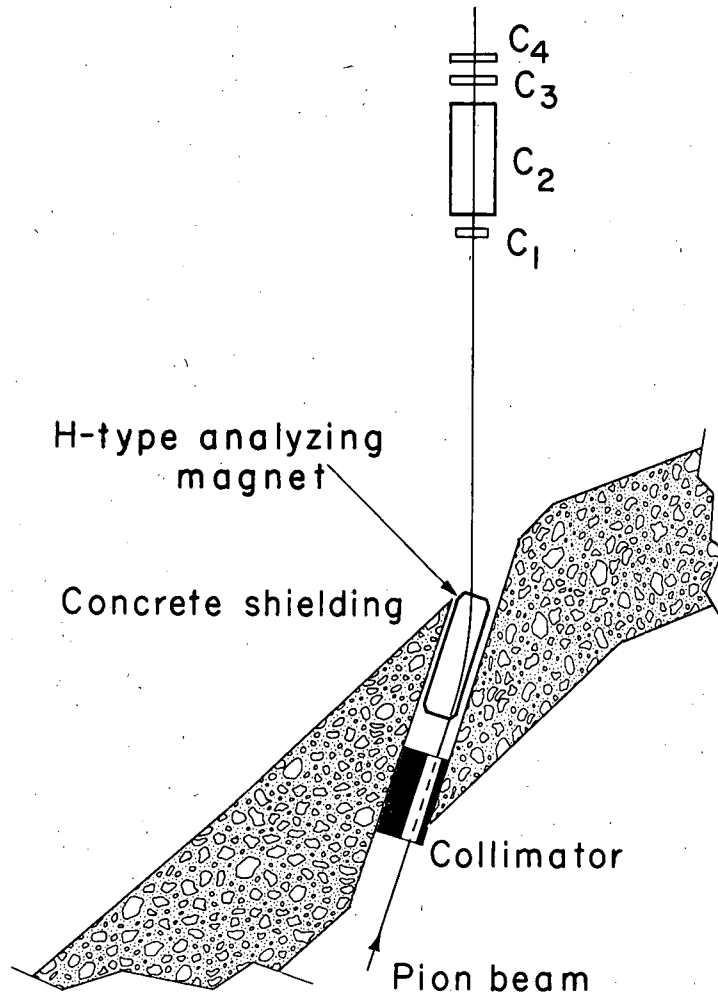
The experimental arrangement is shown in Fig. 2. The momentum of the pion beam was determined by a wire orbit measurement and the momentum spread estimated from the size of the entrance and detection slits.

A block diagram of the counting arrangement is shown in Fig. 3. The efficiency of the Cherenkov counter is defined as the ratio of the number of counts of the monitor scintillators and Cherenkov counter in coincidence ($C_1 + C_2 + C_3 + C_4$) to that of the monitor ($C_1 + C_3 + C_4$). The gain level at which the Cherenkov counter produces a pulse which is recorded was set by the triggering level of the fast discriminator.³ This level was set at 2 volts into the coincidence circuit and was periodically checked by an electronic pulse generator.

The detection efficiency of the Cherenkov counter was measured as a function of the index of refraction for various values of the voltage on the photomultiplier tube. Figure 4 shows the curve obtained in this manner plotted vs. the pressure of the gas in the counter.

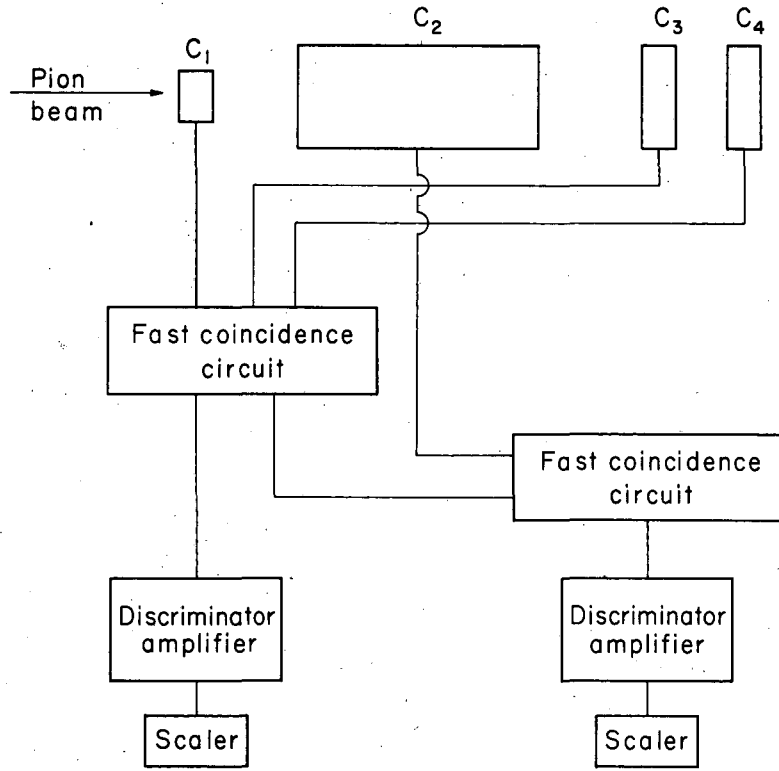
The leading edge of the threshold sensitivity curves shown in Fig. 4 is presumably due to the small electron contamination which is usually present in pion beams. A factor contributing to the slope of the threshold curve is the spread in momentum of the incident pion beam. Figure 5 shows these efficiency curves with the electron background subtracted out and the slopes corrected for the Δp of the pion beam assuming a rectangular distribution in p .

The gain of the photomultiplier tube as a function of voltage was measured independently by the use of a calibrated light source.⁴ The current amplification of the tube as a function of the supply voltage is shown in Fig. 6. The magnitude of the output voltage pulses produced by charged particles traveling through the radiator gas can be written as $V_g = Ag (1 - (1/n^2\beta^2))$, where g is the current amplification of the phototube,



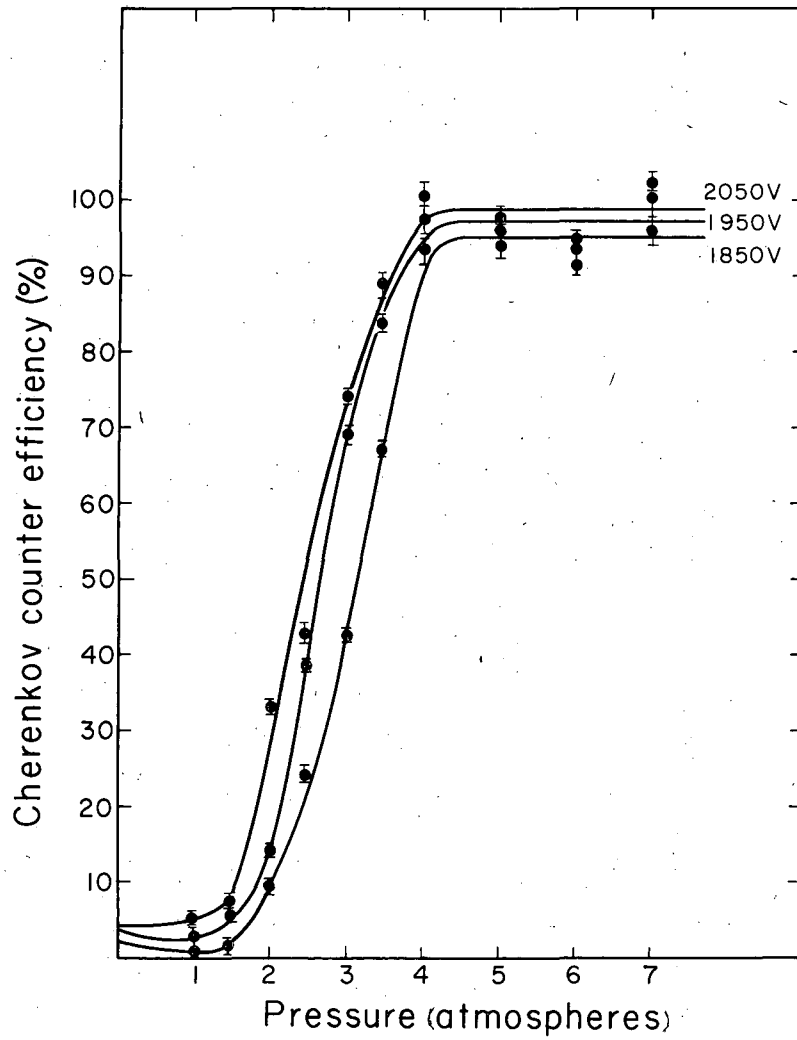
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Fig. 2. Experimental arrangement for threshold measurements at the Bevatron.



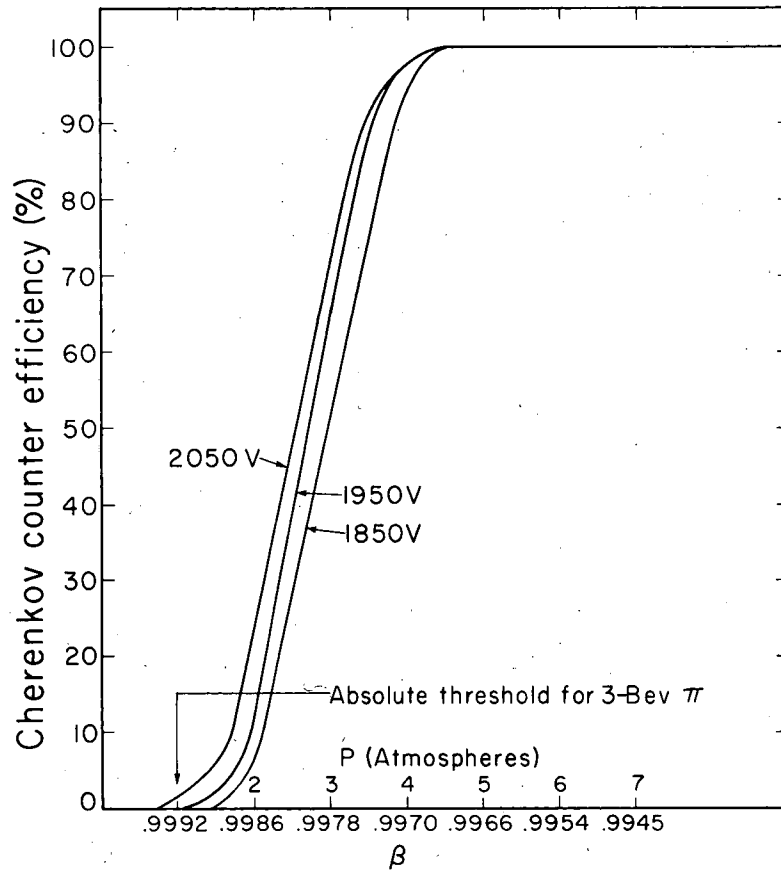
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Fig. 3. Block diagram of electronics.



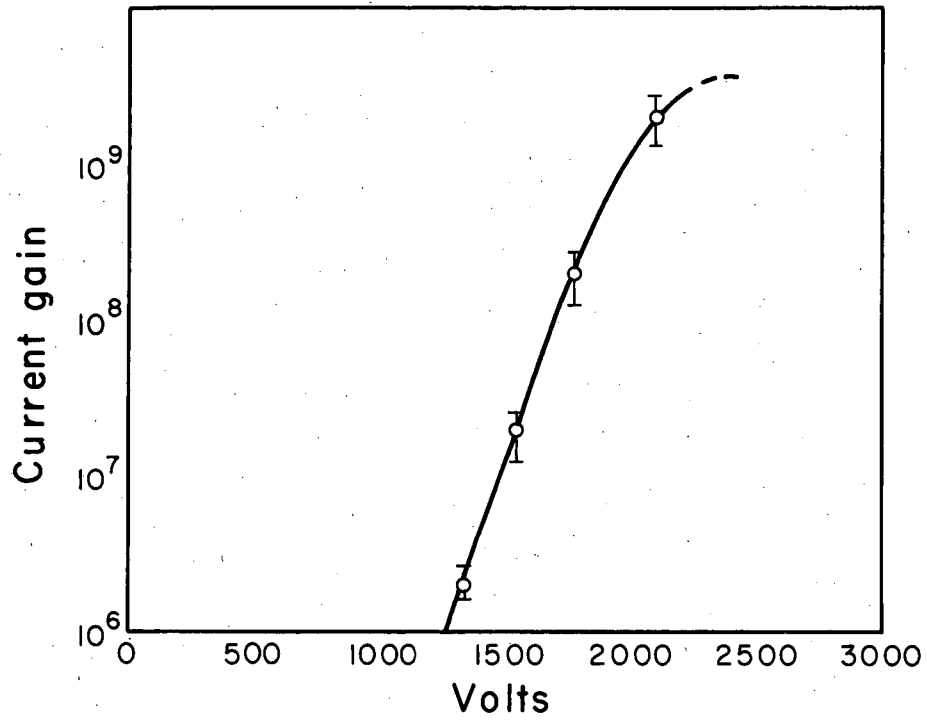
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Fig. 4. Measured detection efficiency of SF₆ Cherenkov counter vs gas pressure for 3-Bev pions. The three curves correspond to different voltages on the photomultiplier tube.



MU-16406

Fig. 5. Corrected efficiency vs pressure curves. The electron background has been subtracted out, and the threshold slopes have been corrected for the energy spread of the pion beam.



MIJ-16407

Fig. 6. Measured current gain vs voltage for the RCA C7232A photomultiplier tube used in the Cherenkov counter.

and A is a constant of the counter which includes the photon-collection efficiency, the transmission through the Lucite window and cathode glass, and the average cathode efficiency. Figure 7 shows the curve V_g plotted for these different gains of the photomultiplier (supply voltages of 2050, 1950, 1850 volts) in arbitrary units. The discrimination level corresponding to a 2-volt output is shown as the horizontal line intersecting the three curves. The intercepts thus give the effective working threshold relative to the absolute threshold, which is defined by the Cherenkov condition $\beta \approx 1/n$. For 1950 volts this effective threshold (90%) corresponds to approximately 270 photons produced in the radiator volume.

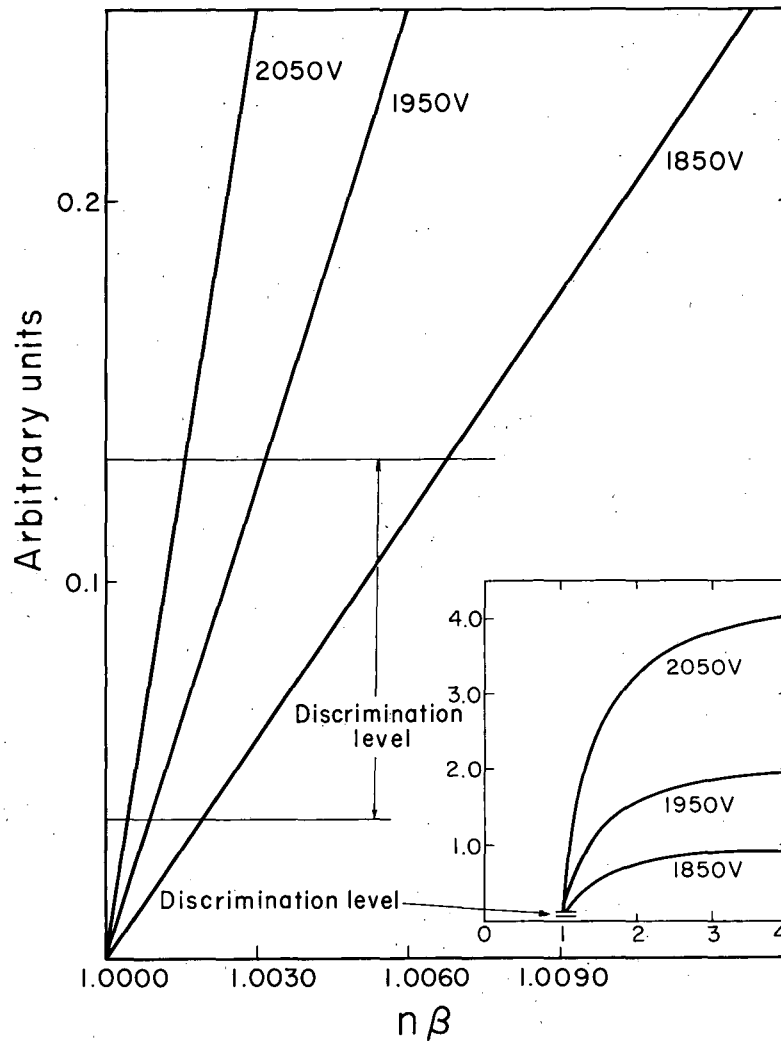
IV. REFRACTIVE INDICES

Accurate indices of refraction for gases appropriate for Cherenkov counter use are not readily available. Table I is a collection of indices of refraction from standard reference sources.

When these counters were built there was some doubt as to whether the equations of the state for the gases used in our counters (SF_6 , CCl_2F_2) and the Lorenz-Lorentz Law were adequate to give the index of refraction to the required accuracy. Therefore, we measured the index of refraction of both these gases by an interferometric method as a function of gas densities. Figures 8 and 9 show the experimental points thus measured for both SF_6 and CCl_2F_2 . The solid lines in the figures are the theoretical curves obtained from the Lorenz-Lorentz Law:

$$R_m \approx \frac{n^2 - 1}{n^2 + 2} \frac{M}{d} \quad (3)$$

where R_m is the molar refractivity,⁵ n the index of refraction, M the molecular weight, and d the density.



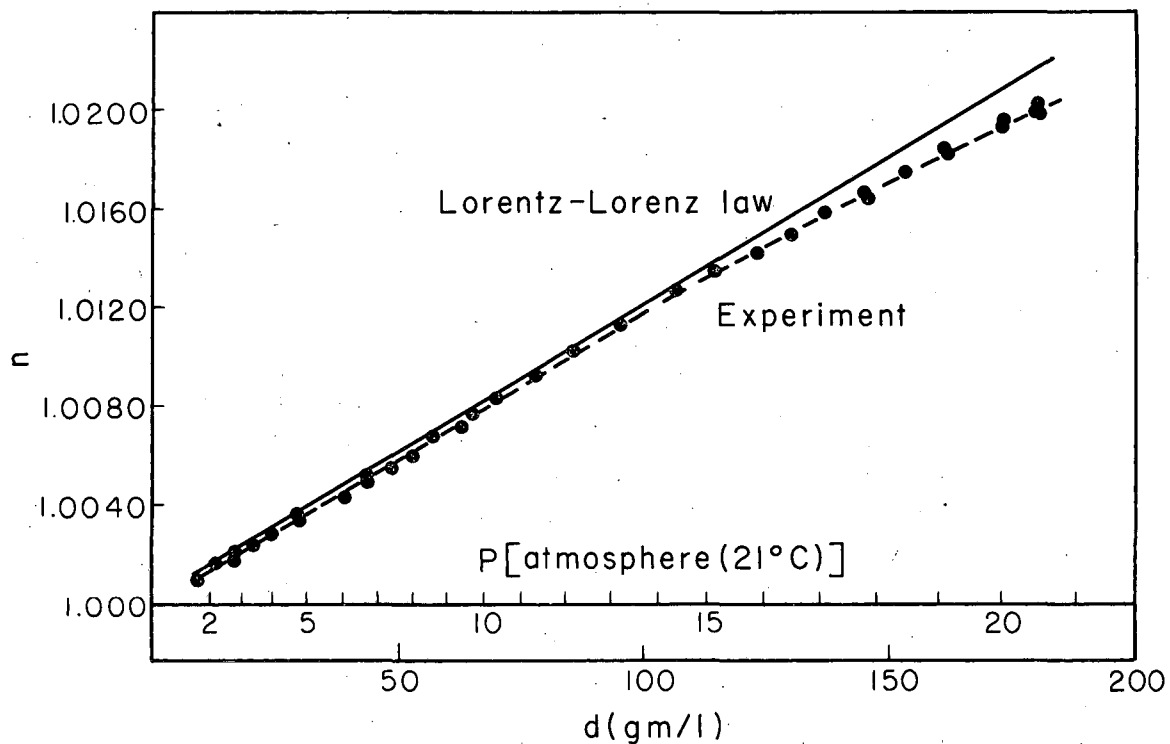
MU-16404

Fig. 7. Output voltage of phototube $V_g = A (1 - (1/n^2\beta^2))$ vs $n\beta$. The horizontal line corresponds to an output voltage of 2 v for a detection efficiency of 90%.

Table I

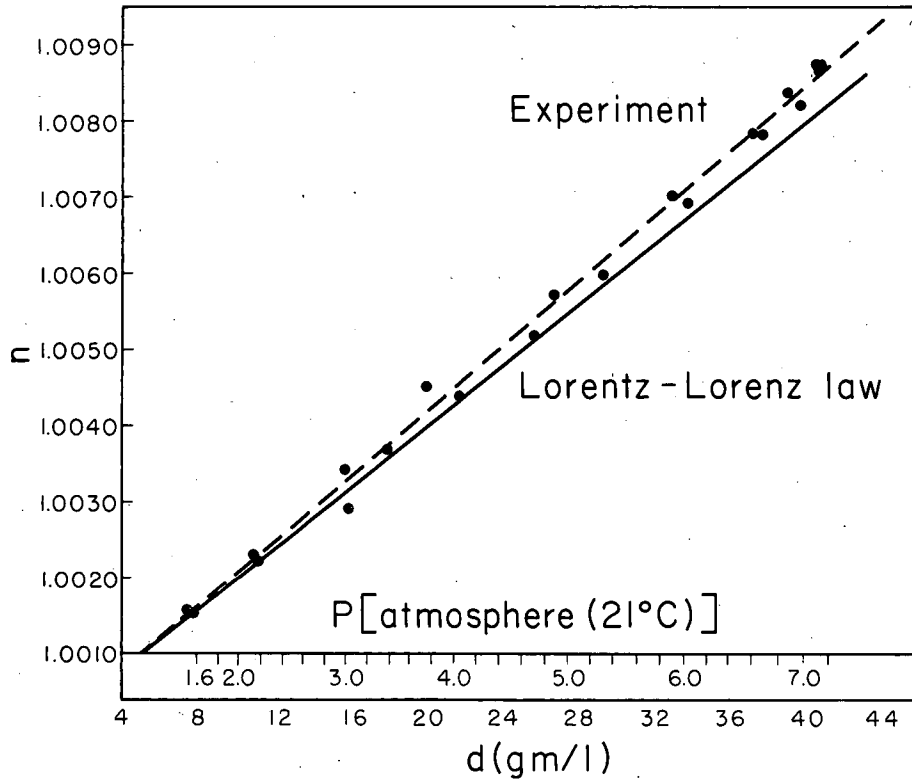
| Index of refraction of gases ^a | | |
|---|---------------------|----------------|
| Values are given for a temperature of 0° C and 760 mm. pressure | | |
| Gas | Index of refraction | Wavelength (A) |
| Acetaldehyde | 1.000296 | 5893 |
| Acetone | 1.001079 | 5893 |
| Acetylene | 1.000610 | 5893 |
| Argon | 1.000283 | 5893 |
| Carbon Dioxide | 1.000449 | 5791 |
| Freon 12 (C Cl ₂ F ₂) | 1.001150 | 5461 |
| Hydrogen iodide | 1.000911 | 5791 |
| Krypton | 1.000427 | 5770 |
| Methane | 1.000439 | 5893 |
| Nitrogen | 1.000296 | 5893 |
| Sulfur hexafluoride | 1.000783 | 5893 |
| Sulfur trioxide | 1.000737 | 5893 |
| Xenon | 1.000702 | 5791 |

Information is taken from International Critical Tables, Vol. VII (McGraw-Hill, New York, 1950), pp. 6 to 11; William E. Forsythe, Smithsonian Physical Tables (Smithsonian Institution, Washington, D.C., 1954), Table 554, 533; and from Fig. 8 and 9 of this paper.



MU-16578

Fig. 8. Index of refraction n of sulphur hexafluoride vs gas density as determined by interferometer measurements and from the Lorentz-Lorenz law. The measurements were made at a wavelength λ of 5400 Å.



MU-16579

Fig. 9. The index of refraction n of $\text{C Cl}_2\text{F}_2$ (Freon 12) vs gas density as determined by interferometry measurements and from the Lorentz-Lorenz law. The measurements were made at a wave length $\lambda = 5400 \text{ \AA}$.

V. CONCLUSION

Two gas-filled counters of the type described above have been in use during the past year as threshold detectors for pions of energy $E_{\pi} > 3 \text{ Bev.}$ ⁶ During this time their performance has been very satisfactory.

The shape of the threshold efficiency curves were measured recently in order to determine whether the efficiency-curve threshold would be sharp enough to permit using these counters as detectors for high-energy particles in elastic-scattering experiments. The minimum energy loss that distinguishes an inelastic event is approximately 150 Mev and corresponds to the production of a single pion, with the remaining particles taking off the maximum energy available from the kinematics of the reaction.

From Fig. 5 and Eq. (2) the number of photons produced for 90% counting efficiency (270) and 10% efficiency (53) at 1950 volts may be calculated. Since the phototube is sensitive only in a limited spectral range these photon numbers are a constant of the counter. Using Eq. (2) we can now calculate the π momentum spread between 90% and 10% efficiency when the pressure in the counter, determining n , is set to give 90% counting efficiency at a given momentum. Table II gives the results of this calculation.

Table II

| Counting Efficiency for π Mesons | | |
|--------------------------------------|----------------------|-----------------------------------|
| p (90%) (Bev/c) | p (10%) (Bev/c) | Δp (90% - 10%) (Mev/c) |
| 3.00 | 2.07 | 930 |
| 2.00 | 1.63 | 370 |
| 1.50 | 1.33 | 170 |
| 1.00 | 0.940 | 60 |

Table II also indicates that these counters are presently most effective in discriminating between elastic and inelastic events in the momentum range of 1.0 to 1.5 Bev/c. This range may be extended to lower momenta by increasing the index of refraction (higher pressures) and to higher momenta by lengthening the radiator.

VI. ACKNOWLEDGMENTS

We would like to thank Professors A. Carl Helmholz and Burton J. Moyer for their support of the experimental program for which these counters were designed. The assistance received from Dr. Wilmot N. Hess and Mr. Julius Solomon, in running the calibration experiment and computing the results is greatly appreciated. Mr. Ralph Nobles was responsible for the index-of-refraction measurements. Finally we would like to thank Mr. Fred Kirsten for the phototube calibration and Mr. Richard Perkins for his help in the construction of the counter.

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