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INCREASED PHOTOELECTRON COLLECTION EFFICIENCY
OF A PHOTOMULTIPLIER IN AN AEROGEL ČERENKOV COUNTER

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ABSTRACT

In a small aerogel Čerenkov counter with diffusing walls, an increase of the photoelectron yield by 40% was measured when the voltage across the cathode to first dynode was increased from 0.6 to 1.7 kV on the 11 cm RCA 8854 photomultiplier tube. A comparison is made with results from other experiments. A general formula for diffusion-type counters is given.

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1. INTRODUCTION

Recently, silica aerogel has been introduced as a Čerenkov radiator medium¹⁾. The yield is reported to be rather low: for large counters, often less than 10 photoelectrons are detected²⁾. In many cases improvements are therefore essential. In this report we describe a way to increase the yield by improving the effective quantum efficiency of the photomultiplier tube.

After the basic photoelectric process in the photocathode of the photomultiplier tube, the photoelectron should be collected to the first dynode. It is known³⁻⁵⁾ that the collection efficiency depends on the photoelectron energy -- and thereby on the incident photon energy -- and on the voltage between the cathode and the first dynode.

A small aerogel Čerenkov counter with diffuse-reflection walls was used to measure the increase in photoelectron collection efficiency as a function of the applied voltage across the cathode to the first dynode.

2. DESCRIPTION OF THE COUNTER AND THE TEST SET-UP

Figure 1 shows the layout of the small aerogel Čerenkov counter. The aerogel had a refractive index of $n = 1.03$. The detector was placed in a negative beam at the CERN Proton Synchrotron, which has a momentum of 1.4 GeV/c; at this momentum the pions produce 84% of the Čerenkov light obtained for $\beta = 1$ particles. The number of electrons in the beam was negligible. The particles traversed 13.5 cm of aerogel. The light was reflected by the diffuse-reflection walls on to an 11 cm diameter photomultiplier, type RCA 8854. This photomultiplier has a bialkali photocathode and a high-gain first dynode, allowing the direct observation of peaks in a pulse-height spectrum corresponding to one, two, and three photoelectrons. The diffuse-reflection walls were made of millipore²⁾.

The photomultiplier was operated with a resistive chain with a variable resistance R_{dyn} across the cathode to the first dynode⁵⁾. The over-all amplification of the tube was kept approximately constant by small adjustments of the voltage over the dynodes. The over-all voltage varied from 2.5 to 3.7 kV.

The voltage across the cathode to the first dynode, V_{dyn} , was varied from 0.5 to 1.8 kV; the value recommended by the manufacturer is 0.67 kV. For each setting of V_{dyn} , pulse-height spectra were recorded both with beam particles and with a light-diode. For calibration purposes, the signal from the light-diode was set to a low level so that peaks corresponding to one, two, and three photoelectrons could be observed. Figure 2 displays a typical pulse-height spectrum obtained with beam particles and with the light-diode. The number of photoelectrons n_e with beam particles was calculated from the centre of the distribution assuming a linear dependence on pulse-height. This assumption was further checked by studying the width-centre relation for larger diode pulses (the width FWHM and the centre C are related to n_e by the relation $\sqrt{n_e} = 2.4 \times C/\text{FWHM}$).

The spectrum obtained with beam particles is wider than that obtained with a light-emitting diode giving the same number of photoelectrons. There are two reasons for this effect; namely, some particles do not traverse the full 13.5 cm length of aerogel, and there is a small contamination of electrons in the beam, the latter giving some 19% more light than the pions.

3. RESULTS AND DISCUSSION

The results are summarized in fig. 3 where n_e is plotted as a function of V_{dyn} (the curve through the data points is hand-drawn to guide the eye), and it can be seen that there is a significant increase in n_e as V_{dyn} increases; from 0.6 to 0.9 kV the measured increase is 16%. In a similar

investigation using nitrogen as radiator⁵⁾ the corresponding increase was found to be 20%. The measurements of Lorenz⁴⁾ show, for the same change of voltage, an increase in the effective quantum efficiency varying from 15% for a photon wavelength of 540 nm to about 50% for wavelengths below 300 nm. As the noise level in the photomultipliers increases rapidly if $V_{\text{dyn}} = 1500 \text{ V}$ ⁴⁾ is exceeded, it is not advisable to use higher voltages than this. When operating this photomultiplier for several months at $V_{\text{dyn}} = 1400 \text{ V}$ no adverse effects on its lifetime have been observed⁶⁾.

In Fig. 4 we plot the increase in effective quantum efficiency as a function of the wavelength for a change of V_{dyn} from 0.87 kV to 1.76 kV⁴⁾. We measure an increase in n_e of 24% over this range of V_{dyn} . As a consistency check, we can estimate how the increase in effective quantum efficiency would affect the measured Čerenkov signal once the wavelength distribution of the Čerenkov signal is known. In Fig. 4 we show as dashed lines the contribution to the Čerenkov signal, using two different light collection systems. In curve (a) the light was focused on to the photomultiplier tube by a mirror, whereas in (b) diffuse-reflection walls were used. The difference comes from the variation with the wavelength of properties such as reflection coefficients of mirror and diffusing walls, and absorption length and diffusion length in the aerogel.

The average gain is obtained by weighing the measured gain with the wavelength distribution of the Čerenkov signal, and so we expect an average increase in the Čerenkov signal of 22% and 28% for the diffuse-reflection system and the mirror system, respectively. These values are in very good agreement with our measured value of 24%.

In order to compare our results with those from other experiments utilizing diffusing-wall aerogel Čerenkov counters, we write:

$$n_e = \frac{n^2 - 1}{n^2} \times L \times K \times \frac{\epsilon}{1 - \eta(1 - \epsilon)}$$

where

- n_e = number of detected photoelectrons,
- n = refractive index of the radiator medium,
- L = particle trajectory length in the radiator,
- K = constant measuring the "goodness" of the Čerenkov light collection and of the photomultiplier,
- ε = ratio of photocathode area to total internal counter area,
- η = reflection coefficient of the diffusing walls (at 400 nm, see Ref. 2).

If there is no absorption in the aerogel, K is given by

$$K = 2\pi \alpha \int q(\lambda) d\lambda / \lambda^2 ,$$

where α is the fine structure constant and $q(\lambda)$ is the effective quantum efficiency of the photocathode. For an RCA 8854 with $V_{\text{dyn}} = 0.76$ kV, we find $K = 104 \text{ cm}^{-1}$. In practice, K depends also on the absorption in the aerogel and has to be determined from experiments. Table 1 lists a number of counters and the corresponding K values^{2,7,8}). The results are also shown in Fig. 5. We conclude that, to a first approximation, the aerogel thickness determines the value of the parameter K ranging from $K \approx 22 \text{ cm}^{-1}$ for 13 cm of aerogel to $K \approx 40 \text{ cm}^{-1}$ for 4 cm of aerogel. This implies that the absorption in the aerogel reduces the output substantially: for 13 cm of aerogel about 20% of the light reaches the photomultiplier, whereas for 4 cm the corresponding figure is 40%.

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Table 1
Comparison of K values for different counters

Counter dimensions (cm ³)	Photo-multiplier used	ϵ (%)	η	Aerogel thickness (cm)	K (cm ⁻¹)	Ref.
52 × 69 × 18	RCA 8854	2.7	1.03	4.5	35	2
"	"	2.7	1.03	9	27	2
"	"	2.7	1.03	13.5	21	2
26 × 27 × 28	"	5	1.03	9	29	8
15 × 11 × 7	"	16	1.03	13.5	24	this paper
15 × 15 × 10	XP 2041	10	1.03	12.5	22	7
"	"	10	1.06	6.2	35	7
"	"	10	1.10	3.7	40	7
17 × 19 × 29	EMI 9813KB	0.78	1.03	5.5	33	2

Figure captions

- Fig. 1 : The aerogel Čerenkov counter. Only the essential parts are shown.
- Fig. 2 : A pulse-height spectrum. Full points are with beam particles and open points with a light-emitting diode. The curves are hand-drawn. The diode spectrum shows the peaks corresponding to the pedestal, and to one, two, and three photoelectrons. The beam spectrum contains some 4% of events with counts in the zero- and one-photoelectron channels. These events are non-pions, interactions, particles missing the aerogel, etc. A few typical error bars are shown. For the diode spectrum, the number of counts per channel is to be multiplied by 100.
- Fig. 3 : The yield of photoelectrons n_e as a function of V_{dyn} , the voltage across the cathode to the first dynode.
- Fig. 4 : The gain in effective quantum efficiency for the RCA 8854 photomultiplier as a function of wavelength for an increase of the voltage across the cathode to the first dynode from 860 V to 1760 V, as deduced by Lorenz⁴⁾. The full line is hand-drawn through the data points. Also shown (as dashed lines a and b) are the signal contributions for two aerogel Čerenkov counters, one with mirrors to collect the light (a), the other with diffusing wall (b). The scale for these curves is arbitrary (see Benot et al., Ref. 2).
- Fig. 5 : The variation of K with the aerogel thickness L from different experiments^{2,7,8)}.

Fig. 1

channel no

Fig. 2

Fig. 3

Fig. 4

Fig. 5