TEST OF A SILICA AEROGEL ČERENKOV COUNTER

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SUMMARY

We have been able to produce samples of silica aerogels. The results of a systematic study of a sample with 4.5 cm diameter and 1.8 cm thickness and refractive index $n = 1.029 \pm 0.002$ are reported.

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1. INTRODUCTION

The new physics opened by the J/ψ discovery has revived a great interest in the identification of K mesons associated with high-energy processes. For example, even a poor π/K separation by time-of-flight was sufficient for the SLAC/LBL experiment at SPEAR to discover new charmed mesons.

On the contrary, the problem of particle identification is far from being satisfactorily solved. This is true, in particular, for experiments to be performed in colliding beam machines (ISR, PEP, PETRA) where the standard techniques, such as high-pressure Čerenkov counters, present big problems because of the momentum range to be investigated and the large solid angle which has to be covered by the detector.

The development of silica aerogel¹⁾ as a Čerenkov radiator²⁾ with refractive indexes in the range 1.01 to 1.07 is of great interest as a possible way out of the problem of particle identification in the low momentum range (1-3.5 GeV/c).

We have built a few silica aerogel samples in order to study the problem encountered in the preparation of this material, and we have tested one sample in a variable momentum beam in order to investigate its properties as a suitable Čerenkov radiator. The results of this test are reported below.

2. THE EXPERIMENTAL SET-UP

The experimental apparatus used in the test run at the CERN PS is shown in Fig. 1, where C1 and C2 are CO₂ gas Čerenkov counters for π/e discrimination and X and Y are scintillation counters to define the beam. The beam momentum could be varied between 0.5 and 3.0 GeV/c.

The aerogel sample was a cylinder of 4.5 cm diameter and 1.8 cm thickness. The optical system through which the light produced in the aerogel was transmitted to the photomultiplier (PM) is shown in Fig. 2. The whole system (aerogel, light-guide, and PM) could be rotated through an angle θ around the PM axis and ϕ in the vertical plane defined by the beam and the PM axis.

The photomultiplier used was a standard Philips 56 UVP operated at a high-voltage setting of -2.3 kV.

Figure 3 shows the electronic logic block diagram used to test the response of the aerogel sample with a pion or electron beam. The signal of the aerogel PM, after being amplified, was sent to an ADC to record the pulse-height information and to a 30 mV threshold discriminator to be counted in coincidence with the pion or electron beam signal, which opened also the 150 nsec wide ADC gate. Another signal from the aerogel discriminator was sent to a delayed coincidence with the beam signal in order to monitor the accidentals rate (always less than 0.5%).

3. RESULTS

We have first optimized the light collection by checking the alignment of the optical system with the beam. This was done with a 2 GeV/c pion beam by varying the angles θ and ϕ and measuring the aerogel detection efficiency. Figure 4 shows the results and the final setting chosen.

Figure 5 shows the detection efficiency of the aerogel as a function of the beam momentum both for electrons and pions. In the available momentum interval the electrons are always above the Čerenkov threshold, and in fact they are detected with an efficiency, independent of the beam momentum, $\epsilon_e = (90 \pm 1)\%$. On the contrary, the detection efficiency for pions shows the typical threshold behaviour of the Čerenkov radiation. This fact, together with the angular dependence of the light collection (shown in Fig. 4), proves that our "home-made" silica aerogel behaves indeed as a good Čerenkov radiator.

The momentum threshold for pions, derived from Fig. 5, is 580 ± 20 MeV/c. The refractive index of the aerogel sample calculated from the above threshold value is $n = 1.029 \pm 0.002$.

The total number of photons produced in 2.5 cm of aerogel (our sample at 45° with respect to beam line) by a $\beta = 1$ particle is calculated to be $N_\gamma = 31 \pm 2$, with photons on the wavelength interval³⁾ (3700-4500)Å.

The light-collection efficiency has been calculated by a ray-tracing program⁴⁾ simulating the situation of Fig. 2. An upper limit to the light-collection efficiency is given by the ideal case of a perfectly transparent aerogel and a zero divergence beam or radiating particles: in this case, with a 90% reflectivity of the aluminium surfaces, we obtain an efficiency $\epsilon_c^m = 75\%$. A lower limit can be obtained by making particles radiate isotropically in the aerogel, keeping all the other conditions the same: in this case the light-collection efficiency is $\epsilon_c^m = 39\%$. On the other hand, if we use for the absorption coefficient of the aerogel the value given by Bourdinaud et al.⁵⁾, $1/\lambda_a = 0.08 \text{ cm}^{-1}$, the light-collection efficiency turns out to be $\epsilon_c^a = 59\%$. Taking into account other factors such as beam divergence or surface irregularities, the calculated variations never exceed $\pm 10\%$.

On the above grounds the light-collection efficiency of the optical system is $\epsilon_c = (60 \pm 10)\%$. If we take for the photoconversion efficiency the value given for the 56 UVP PM, $\epsilon_e^{\text{ph}} = 12\%$, the expected number of photoelectrons collected by the PM is

$$N_{\text{th}}^{\text{ph.el.}} = N_\gamma \cdot \epsilon_c \cdot \epsilon_e^{\text{ph}} = 2.2 \pm 0.3.$$

The measured number of photoelectrons compares very well with the above evaluation and is checked in two ways. The first is by using the measured efficiency given in Fig. 5. This method yields the value

$$N_{\text{exp}}^{\text{ph.el.}}(1, \text{UVP}) = 2.3 \pm 0.1 .$$

The second method uses the fit with a Poisson distribution of the pulse-height spectrum produced by a high-energy electron beam ($E_e = 1 \text{ GeV/c}$). This method gives

$$N_{\text{exp}}^{\text{ph.el.}}(2, \text{UVP}) = 2.18 \pm 0.04 .$$

The spectrum and the fit are shown in Fig. 6.

Keeping all experimental conditions the same, we have measured the value of $N_{\text{exp}}^{\text{ph.el.}}$ for the case of a Philips 56 AVP photomultiplier, using the second method mentioned above. The result is

$$N_{\text{exp}}^{\text{ph.el.}}(2, \text{AVP}) = 1.76 \pm 0.19 .$$

This result is in the direction expected; the ultraviolet light is indeed poorly transmitted through silica aerogels and therefore the UVP tube does not show such a great advantage with respect to the AVP one. In fact the increase in the number of photoelectrons is $\sim 24\%$, while the expected value, based on the known properties of these tubes, would be twice as much.

Notice that with our simple light-collection optics the number of photoelectrons we have compares very well with the photostatistics obtained by Bourdinaud et al.⁵⁾ using an elaborated optical light-collection system.

4. CONCLUSIONS

From the results obtained we conclude that it is possible to produce good-quality aerogel samples with a refractive index as low as 1.03, and that their behaviour as Čerenkov radiator would allow hadron identification to be extended to a momentum range not easily accessible with standard techniques.

REFERENCES AND NOTES

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- 3) J. Litt and R. Meunier, Annu. Rev. Nuclear Sci. 23, 1 (1973). On page 3 the formula given for the number of photons per unit length is

$$dN_{\gamma}/dL = 2\pi\alpha Z^2 \int_{\lambda_2}^{\lambda_1} [1 - (1/\beta^2 n^2)] (d\lambda/\lambda^2) ,$$

where α is the fine structure constant, Ze the charge of the radiating particle; λ_1 and λ_2 have been taken as 3700 and 4500 Å, respectively.

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- 5) M. Bourdinaud, J.B. Cheze and J.C. Thevenin, Nuclear Instrum. Methods 136, 99 (1976).

Figure captions

- Fig. 1 : Experimental set-up (not to scale). C_1 , C_2 are gas Čerenkov counters, X and Y, scintillation counters to define the beam. The aerogel is placed in between the second gas Čerenkov counter and Y with a 45° inclination with respect to the beam axis.
- Fig. 2 : A cross-section of the optical system through which the light produced in the aerogel sample was transmitted to the 56 UVP photomultiplier.
- Fig. 3 : Electronic logic block diagram.
- Fig. 4 : Detection efficiency for 2 GeV/c pions when the whole system (aerogel, light-guide, and PM) was rotated through an angle θ (around the PM axis) and through an angle ϕ (in the plane defined by the beam and the PM axis).
- Fig. 5 : The detection efficiency of the aerogel as a function of the beam momentum for electrons (open circles) and pions (full squares).
- Fig. 6 : The histogram is the aerogel pulse-height spectrum for 1 GeV/c electrons. The curve is the best fit to the data using a Poisson distribution.

Fig. 1

Fig. 2

Fig. 3

Fig. 4

Fig. 5

Fig. 6