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Diffuse reflectivity of Tyvek in air and water, and anisotropical effects

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The reflectivity of Tyvek in air and water as a function of incidence and reflection angles is reported. The measurements were made for $\lambda = 488nm$ and $\lambda = 632.8nm$. Optical anisotropies of the material are revealed when a rotation is made about the normal vector of the sample.

1. Introduction

In the design of the water Cherenkov detectors of the Pierre Auger project it is important to consider the following aspects: The interaction of relativistic particles with water, the absorption length of light in water, the reflectivity of the material used to cover the inner surface of the detector and the efficiency of the photodetectors [1]. Tyvek will be used to cover the inner surface of the Cherenkov detectors, therefore, the information about the Tyvek optical properties is an important factor to take into account in simulations and reconstruction of ultra high energy cosmic rays detected through the Cherenkov light emitted by the air shower secondary particles penetrating the water detectors. Tyvek is made up of millions of polyethylene fibers randomly oriented that overlap, is chemically inert and resists water penetration [2]. We focused our attention on the diffuse reflectivity of Tyvek and the influence of the anisotropies of the material on these measurements.

2. Experimental set-up and procedure

The experimental design is shown in Fig. 1. Here the main measured parameters are the incidence angle θ_i, the reflection angle θ_r and the amount of reflected light in that direction I_t.

In order to get the data, we built an automatic system to measure the diffuse reflectivity as a function of θ_r with steps of 1.8^0 and for the following incident angles: $0^0, 15^0, 30^0, 45^0, 60^0$ and 75^0. As photodetector, an NPN silicon phototransistor was used, whose assembly was designed to allow to immerse it in water. We worked at two different wavelengths: one in the blue region ($\lambda = 488nm$, Argon laser) and another one in the red region ($\lambda = 632.8nm$, He-Ne laser). The distance between the laser and the sample was 35 cm while that between the Tyvek and the detector was 2.5 cm.

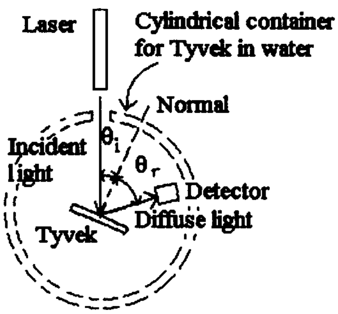

Figure 1. Experimental set-up.

For the measurements in pure water we used a cylindrical container whose inner surface was sprayed with black paint, in order to avoid undesirable reflections. This container was provided with a glass window to allow the incidence of the laser beam on the sample. For the measurements of the anisotropical effects we kept θ_i constant (75^0) and rotated the sample by an angle α about

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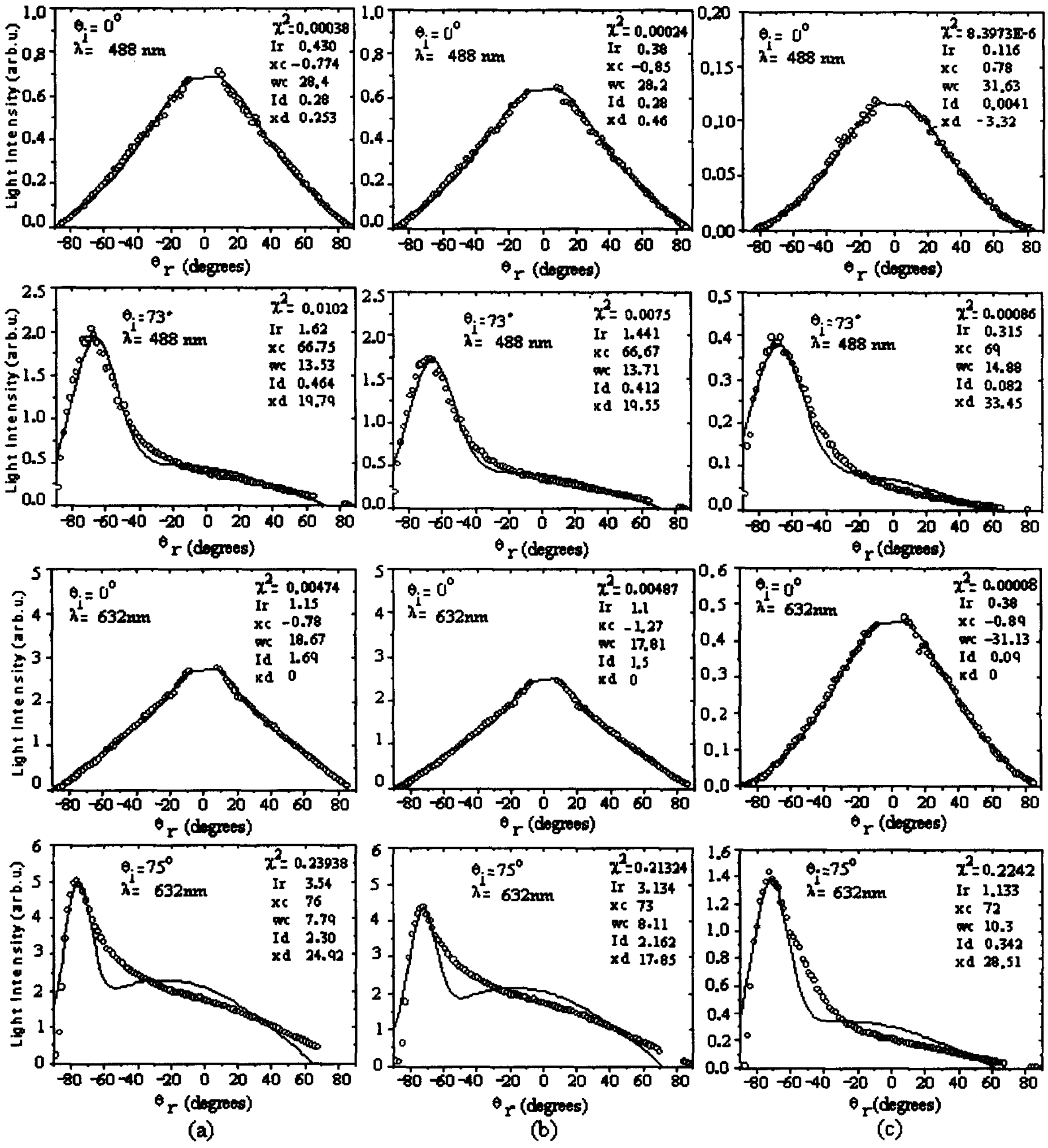

Figure 2. Diffuse reflectivity spectrum of Tyvek as a function of θ_r for $\lambda = 488nm, 632.8nm$, and $\theta_i = 0^o, 75^o$ for Tyvek: (a) in air, (b) inside the cylindrical container, and (c) in water. The circles represent the experimental data while the solid line the fit by using the relation (1).

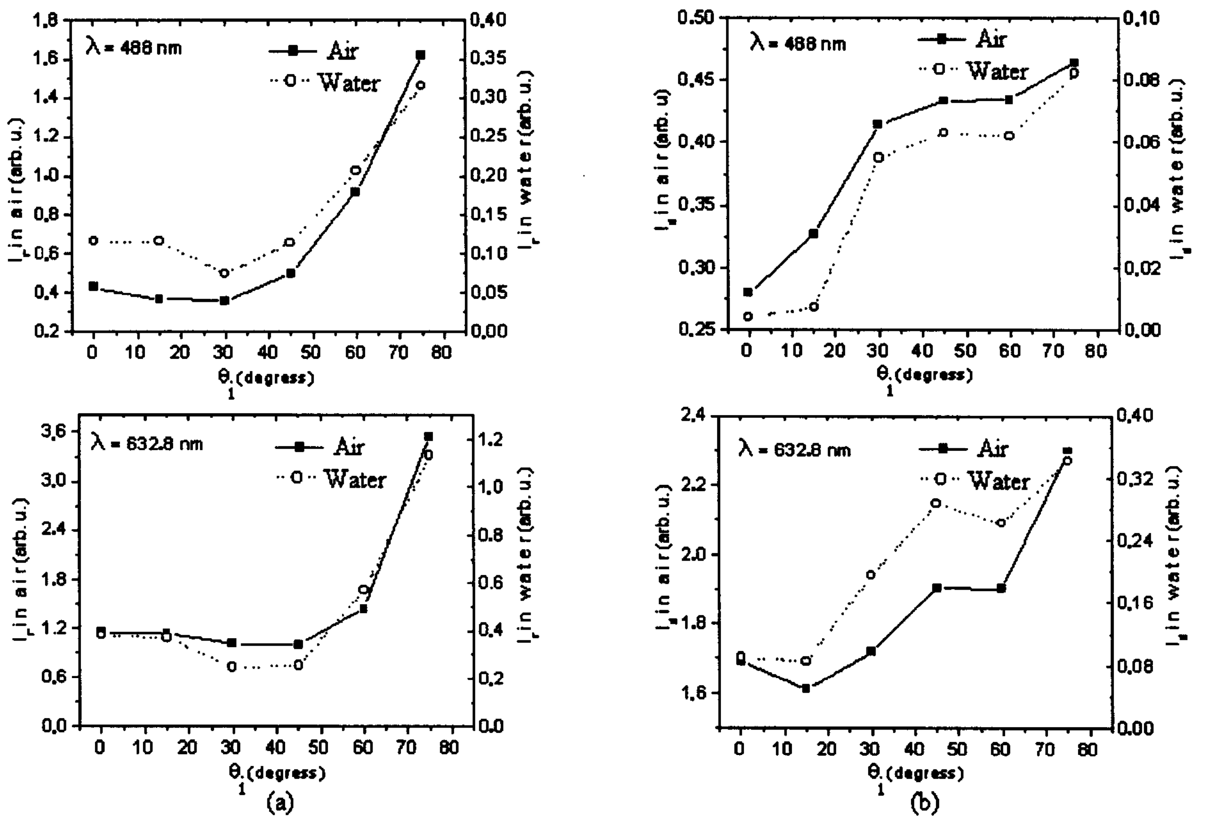

Figure 3. (a) I_r and (b) I_d as a function of θ_i

its normal vector.

3. Analysis and Results

The graphs for diffuse reflectivity of Tyvek in air and inside the cylindrical container with and without water are shown in Fig. 2 for $\theta_i = 0^0$ and 75^0. In Fig. 2, units are arbitrary but the same scale is used for all the cases. The difference in intensity when changing the laser beam arises from the spectral responsivity of the phototransistor and the nominal laser power. At $\lambda = 632.8nm$ the responsivity is $0.25 Amperes/Watt$ and the He-Ne laser nominal power is $2mW$, while at $\lambda = 488nm$ the responsivity is $0.18 Amperes/Watt$ and the Ar laser nominal power is $11mW$. In order to fit the data (see Fig. 2), we proposed the following relation:

$$I_t(\theta_i, \theta_r) = I_r e^{\frac{-(\theta_r + x_c)^2}{2w_c^2}} + I_d cos(\theta_r + x_d) \qquad (1)$$

by similarity with the relations proposed by Hasenbalg et al [3], and Filevich et al [4], where it is assumed a cosine function (suggested by Lambert's law) to fit the diffuse light, and a gaussian term to fit the peak (which has a specular contribution). Here, x_c gives us the position of the I_r component while x_d is a phase displacement of the cosine function.

The decrease of the diffuse reflectivity when the sample is immersed in water is mainly associated with the increase of the refractive index of the incidence medium, from 1 in air to 1.34 (for $\lambda = 488nm$) or 1.331 (for $\lambda = 632.8nm$) in water [5]. The I_r and I_d parameters are identified as the specular and diffuse components, respecti-

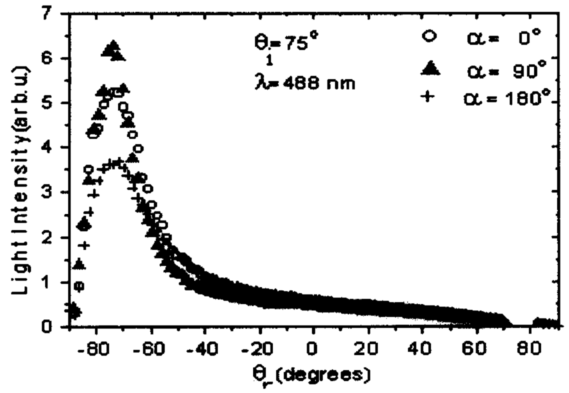

Figure 4. Optical anisotropic effects on the diffuse reflectivity.

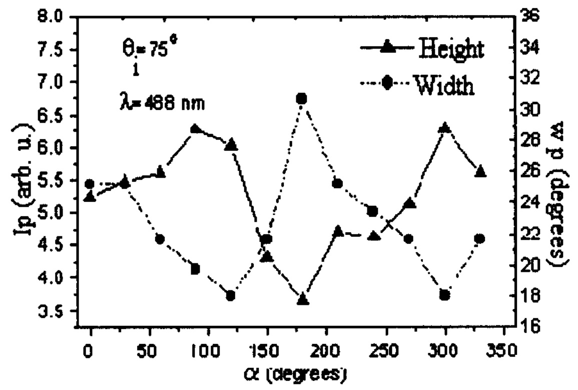

Figure 5. Changes of the diffuse reflectivity parameters under a rotation of the sample by an angle α.

vely, and are plotted in Fig. 3. From these curves, we can see that: 1)The specular component has a decreasing behavior from $\theta_i = 0^0$ to 30^0 or 45^0 (the difference can reach up to 10 %) and then, it increases when going from $\theta_i = 45^0$ to 75^0. This behavior is similar to that of the p component of the classical specular reflectivity between two media [6]. 2)The diffuse component has an opposite behavior. The optical anisotropies of Tyvek are shown in Fig. 4 and 5 for $\lambda = 488nm$. The shape of the graphs changes under a rotation α. The height (I_p) and half width (w_p) of the diffuse reflectivity as a function of α are shown in Fig. 5. Clearly, an anticorrelation between I_p and w_p is observed, which means that: The larger the specular component (I_d), the smaller the diffuse part (w_d). Note that I_p can decrease up to 43% of its maximum value.

4. Conclusions

By building a simple automatized system involving the control of a step motor and data acquisition, the diffuse reflectivity of Tyvek has been carefully obtained. The influence of optical anisotropies has been determined and should not be neglected in the simulation studies of the Cherenkov radiation involving Tyvek. This effect must be studied for different surface regions on Tyvek.

5. Acknowledgements

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