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Influence of water on optical parameters of aerogel ☆

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ABSTRACT

Influence of water adsorbed in aerogel on its optical parameters has been studied. For the first time it was obtained that a very little amount of adsorbed water results in a degradation of the light absorption length (L_{abs}). The time constant of L_{abs} degradation process has been measured for the first time. It is about 20 days and greater than the time constant of a water adsorption process by two orders of magnitude. L_{abs} degradation can be explained by a contamination of aerogel by metals such as Fe and Co. Data on the influence of water on the refractive index and the light scattering length are presented. The procedure of aerogel selection for use in Cherenkov counters with the diffusive light collection has been suggested.

1. Introduction

Silica aerogel was used and is used now in Cherenkov detectors of different types [1]. The production of silica aerogel in Novosibirsk was started in 1986 by the collaboration of Boreskov Institute of Catalysis and Budker Institute of Nuclear Physics. Several particle identification systems such as aerogel threshold counters for the KEDR detector and for the SND detector, aerogel RICH detectors for the LHCb experiment and for the AMS02 project apply aerogel produced in Novosibirsk [2].

In 2004 the new promising type of RICH detectors based on focusing aerogel (FARICH) was suggested [3,4]. According to the Monte Carlo (MC) simulation of FARICH high precision of velocity measurement can be achieved ($\Delta\beta/\beta \approx 5 \times 10^{-4}$) [4].

The largest amount of Novosibirsk aerogel is used in aerogel threshold counters of the KEDR detector. This system consists of 160 ASHIPH (Aerogel SHifter PHotomultiplier) counters and contains 1000 l of aerogel with the refractive index of 1.05 [2,5].

Aerogel produced in Novosibirsk is a hygroscopic material. Internal surface of aerogel with a volume of 1 cm^3 is greater than external one by a factor of 10^6. Influence of water adsorbed in aerogel on its main optical parameters has been studied. All experiments and calculations were carried out for hygroscopic Novosibirsk aerogel with the refractive index $n = 1.05$.

2. Water adsorption. Refractive index and light scattering length.

The adsorption of water by aerogel is rather rapid and reversible process. In Fig. 1 the time dependence of the aerogel mass increase during water adsorption is presented. Atmospheric conditions in this test were the following: relative humidity 7%, air temperature 25 °C. The time dependence was fitted by an exponent plus some constant. The constant level depends on atmospheric conditions. The time constant of aerogel mass change due to the water adsorption or desorption is 1–2 h. The mean amount of absorbed water in aerogel during its storage without a control of atmospheric conditions is 1–2% of aerogel mass. The maximum is 3–4% [6].

The adsorption of water in aerogel is able to increase aerogel refractive index. Simple estimations show that 1% increase of aerogel mass due to water results in increase of $n - 1$ by 1.5%.

The measurement procedure of the light scattering length (L_{sc}) was described in Ref. [7]. For aerogel samples impregnated with water up to 1.5% of their masses we have not observed the degradation of L_{sc} during 3000 h within the measurement accuracy of 10%. L_{sc} of tested blocks was in the range from 40 to 50 mm at 400 nm wavelength.

3. Light absorption length

The light collection (LC) in ASHIPH counters depends on the light absorption length (L_{abs}), the light scattering length, the configuration of the box and the reflective index of the box walls (r). The long term stability of ASHIPH counters was studied and origins of the degradation were investigated in our previous

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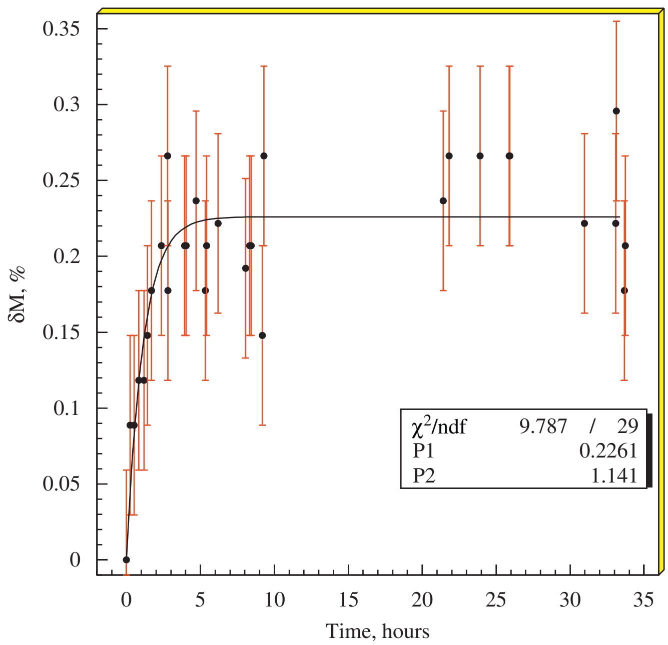

Fig. 1. The time dependence of mass during ($\delta M, \%$) water adsorption process.

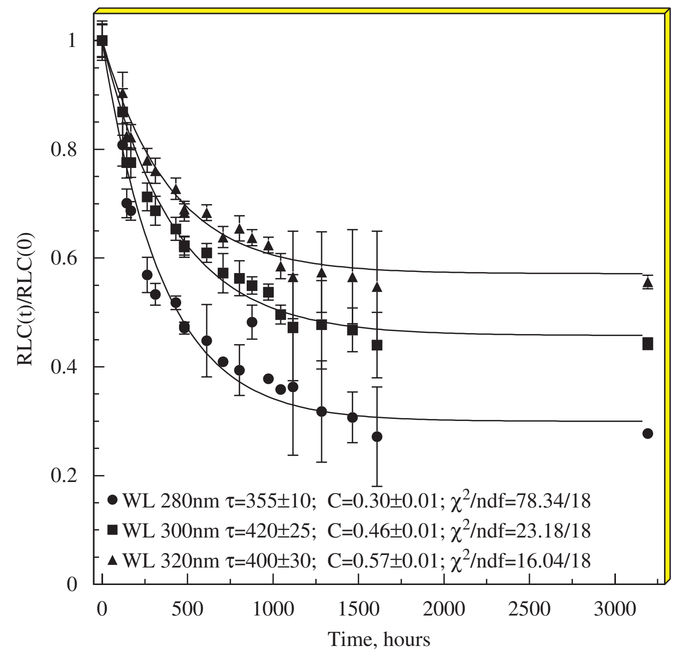

Fig. 2. Normalized *RLC* as a function of time for three light wavelengths. Parameters of the fit are shown in the legend.

work [2]. The decrease of the number of photoelectrons (N_{pe}) in ASHIPH counters due to aerogel degradation was in the range of 3–35%. Since we have not found any degradation of L_{sc} and the dependence of LC on L_{abs} is more drastic than on L_{sc} this phenomena excite us to investigate the influence of absorbed water on the light absorption length.

To obtain L_{abs} we measure the relative coefficient of the light collection (*RLC*) at the light wavelengths $\lambda = 280-500\,\text{nm}$:

$$RLC = \frac{LC_{aer}(r, L_{sc}(\lambda), L_{abs}(\lambda))}{LC_{box}(r)},$$

where LC_{aer} and LC_{box} are the light collection coefficients in the testing box with and without aerogel, respectively. L_{abs} can be extracted from this relation with the help of Monte Carlo simulation. These procedures are described in Refs. [6–8].

Earlier it was found that L_{abs} in aerogel degrades after exposure of aerogel to atmospheric conditions and can be restored by baking in an oven [6]. We have tested 12 aerogel blocks ($53 \times 53 \times 25\,\text{mm}^3$) impregnated with different amount of water from 0.25% to 1.5%. In Fig. 2 the time dependence of the *RLC* is shown for three light wavelengths (280, 300 and 320 nm). The data are fitted by an exponent which goes to some constant level:

$$RLC = (1 - C) \cdot e^{-t/\tau} + C,$$

where τ and C are free parameters called the time constant and the constant level, respectively. We assume that the time constant τ of L_{abs} degradation is the same as for the RLC decrease because we have not found L_{sc} degradation. This time constant is equal to 350–420 h (Fig. 2). That is much greater than the time constant of the water adsorption process (1–2 h). The value of τ was measured for the first time. We have not found a correlation between the time constant of L_{abs} and the amount of adsorbed water for aerogel mass increase from 0.25% to 1.5%.

The reason of L_{abs} degradation due to water adsorption could be a presence of impurities in aerogel such as Fe, Co, Cu, Mn, etc. These metals appear in aerogel during the production procedure and from the row materials. They are able to attract water molecules and create some complex conjunctions which absorb

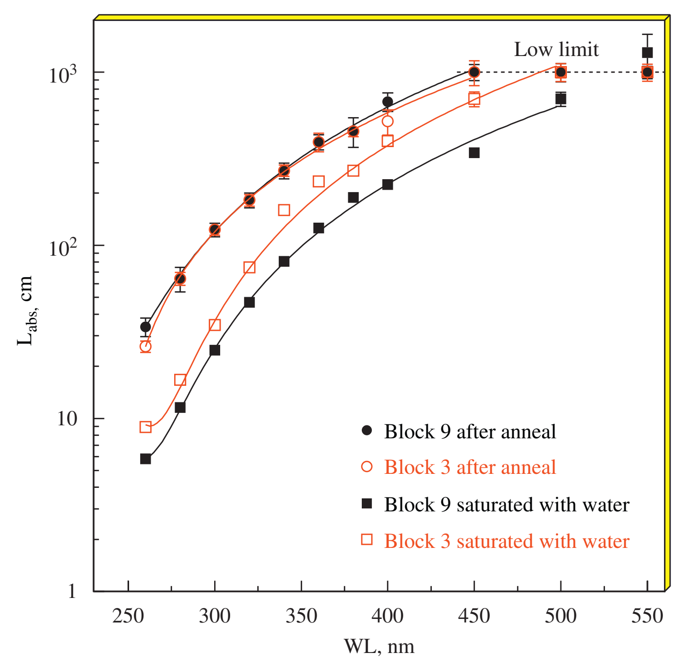

Fig. 3. The L_{abs} dependence on wavelength for two aerogel blocks after baking and after impregnating with water.

light in the visible wavelength region while separately these elements and water do not absorb light in the visible region as well as SiO_2. According to the theoretical estimations amount of adsorbed water equal to 10^{-6} of aerogel mass is enough to explain maximum L_{abs} degradation.

In Fig. 3 the dependencies of L_{abs} on the light wavelength are shown for two blocks after impregnation with water and after baking in the oven. The amount of adsorbed water equals to $0.4 \pm 0.1\%$ and $0.5 \pm 0.1\%$ for the blocks 3 and 9, respectively. The reason of the difference between L_{abs} for these two blocks can be a different concentration of metal admixtures.

The L_{abs} data for the blocks 3 and 9 were used in MC simulation of the real ASHIPH counter of the KEDR detector [8,9]. We obtained that for a counter filled with the aerogel like block 9 the N_{pe} change due to L_{abs} degradation would be 33%, for a counter filled with the aerogel like block 3 it would be 23%. These results are in agreement with the experimental data mentioned above.

We suggest the new procedure of aerogel selection for use in counters with the diffusive light collection. According to the old one aerogel with a high *RLC* was selected for use in the counters just after baking. Now we suggest to select aerogel that have a high *RLC* after being impregnated with water (2–3 months after exposure to the atmospheric conditions). In this case it is possible to select aerogel with a small concentration of impurities and consequently less sensitive to water adsorbed from the environment.

4. Conclusion

The influence of a water on main aerogel optical parameters has been studied.

The time constant of water adsorption and desorption is 1–2 h.

No degradation of the light scattering length has been found.

The time constant characterizing L_{abs} degradation of aerogel has been measured for the first time. It is about 20 days. The adsorption of water amount less than 0.25% of aerogel mass is enough to have maximum L_{abs} degradation. L_{abs} degradation can be explained by the presence in the aerogel of metal impurities such as Fe, Co, Cu, Mn, etc.

The new procedure of aerogel selection for use in Cherenkov counters with the diffusive light collection has been suggested.

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