

# Optical transmittance of silica aerogel

A. Hakobyan\*<sup>1</sup>, A. Mkrtchyan<sup>1</sup>, and D. Khurshudyan<sup>1</sup>

<sup>1</sup>*Alikhanyan National Science Laboratory, Yerevan, Armenia*

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## Abstract

This paper presents the investigation of aerogel Cherenkov radiation detectors and the optical characterization of aerogel samples within the framework of the SPD experiment at the NICA accelerator complex, which is under construction at the Joint Institute for Nuclear Research (Dubna, Russia). The transmittance of aerogel samples was measured at the A. Alikhanyan National Science Laboratory (AANL) (Yerevan Physics Institute). Longitudinal transmittance measurements were performed for two distinct aerogel samples. Data analysis and visualization of results were carried out using the OriginPro 8.5 and ROOT software packages. The obtained results were compared with analogous studies performed at other research centers in order to evaluate the reliability, consistency and accuracy of the measurements.

*Keywords:* aerogel, SPD, NICA, detector, transmittance measurement

DOI: [10.54546/NaturalSciRev.100602](https://doi.org/10.54546/NaturalSciRev.100602)

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## 1. Introduction

NICA (Nuclotron-based Ion Collider fAcility) is a new accelerator complex developed at the Joint Institute for Nuclear Research (Dubna, Russia) for the study of properties of dense baryonic matter. NICA will provide a wide range of particle and nuclear beams, from protons and polarized deuterons to heavy ions (such as gold). Heavy ions will be accelerated up to 4.5 GeV/nucleon and protons — up to 12.6 GeV.

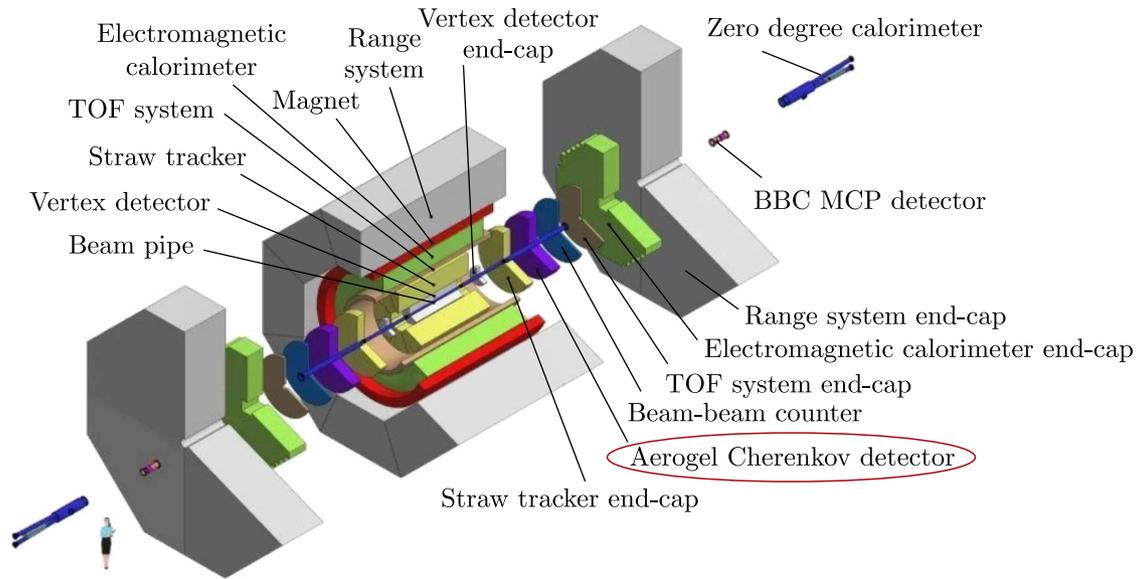
The NICA collider rings will have two interaction points: one for heavy-ion studies using the Multi-Purpose Detector (MPD) and the other for studying spin phenomena with polarized beams within the Spin Physics Detector (SPD) experiment.

The SPD Collaboration proposes to install a universal detector at the second interaction point of the NICA collider to investigate the spin structure of the proton and deuteron using polarized proton and deuteron beams. The main goal is to understand how spin influences the distribution and dynamics of quarks and gluons inside nucleons. The expected center-of-mass collision energy will reach up to 27 GeV, with a luminosity of  $10^{32} \text{ cm}^{-2} \cdot \text{s}^{-1}$ .

The capability of the NICA complex to perform such studies with polarized deuteron beams at high energies is unique.

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\*Corresponding author e-mail address: [argine.hakobyan@yerphi.am](mailto:argine.hakobyan@yerphi.am), [argine.s.hakobyan@gmail.com](mailto:argine.s.hakobyan@gmail.com)



**Figure 1.** The schematic structure of the SPD detector.

The SPD [1] is a universal detector with a  $4\pi$  solid angle coverage (Figure 1), which will provide unique capabilities for particle tracking and identification based on state-of-the-art technologies. The implementation of an aerogel Cherenkov detector will significantly extend the momentum range of particle identification (PID). According to the SPD physics program, the primary task of the PID system is the separation of pions and kaons in the final states at momenta above  $1.5 \text{ GeV}/c$ , where neither the time-of-flight (TOF) nor the  $dE/dx$  methods are sufficient. Cherenkov counters represent the most suitable solution for this problem.

Aerogels are particularly advantageous as Cherenkov radiators because of their high transparency and tunable refractive index, which allow them to effectively bridge the gap between gaseous and liquid radiators.

## 2. Aerogel production and properties

Aerogel was first synthesized in 1931. It consists of approximately 99.8% air and 0.2% silica, has a highly porous structure, good optical transmittance, and a low refractive index, making it particularly suitable for Cherenkov detectors [2].

At present, aerogel production technology has been mastered mainly at two centers: Matsushita Electric Industrial Co. (Japan) and the Budker Institute of Nuclear Physics (BINP) (Russia).

Aerogel has a wide range of applications, including the usage as a filter for gases and liquids, as a thermal insulator, and as a radiator material in Cherenkov counters for high-energy physics experiments. It bridges the gap in refractive indices between gases and liquids, making it an effective radiator for particle identification. For example, it enables  $\pi/K$  meson separation in the momentum range from a few hundred  $\text{MeV}/c$  up to about  $3 \text{ GeV}/c$ .

The refractive index of aerogel can be tuned in the range from 1.0006 to about 1.25. For aerogel materials of different densities  $\rho$ , the refractive index  $n$  can be expressed as

$$n = 1 + 0.21 \times \rho.$$

The precise value of the refractive index is determined during the production stage, and its choice depends on the momentum range relevant for the given physics task, where efficient

particle separation is required. The momentum threshold  $p$  for Cherenkov radiation emission by a particle of mass  $m$  is given by

$$p = \frac{m}{\sqrt{n^2 - 1}}.$$

Table 1 presents the threshold momenta for particles in aerogels with different refractive indices. Particle momentum unit: GeV/ $c$ .

**Table 1**

$n$	1.05	1.04	1.03	1.02	1.015	1.01
$\pi$	0.44	0.49	0.57	0.70	0.80	0.99
$K$	1.54	1.73	2.00	2.46	2.84	3.48
$p$	2.93	3.29	3.80	4.67	5.40	6.62

Aerogel exhibits a relatively short light scattering length of 12–40 mm (depending on the wavelength). Therefore, in thick aerogel radiators, the directionality of Cherenkov light cannot be exploited, as it rapidly diminishes after emission. For this reason, the inner surfaces of the detector walls are covered with diffusively reflecting materials to ensure effective light collection. Another advantage of aerogel is the absence of noticeable scintillation emission.

No significant deterioration of the optical properties (transmittance, refractive index) has been observed for aerogels exposed to radiation doses up to approximately 10 Mrad [3].

Aerogel threshold Cherenkov counters have already been successfully implemented in many experiments, such as KEDR (BINP, Novosibirsk) [4, 5], Belle (KEKB, Tsukuba) [6, 7], DIRAC [8], and elsewhere. In the Belle experiment, aerogel threshold Cherenkov counters with refractive indices in the range of 1.010–1.030 provided  $\pi/K$  separation up to momenta of 3.5 GeV/ $c$ . In the KEDR detector, the aerogel counters with  $n = 1.05$  ensured  $\pi/K$  separation in the momentum range of 0.6–1.5 GeV/ $c$ . In the DIRAC experiment, aerogel radiators with refractive indices of 1.015 and 1.008 were used. As a result, for the kaons, an average of 6.9 photoelectrons were recorded in the 4.0–5.2 GeV/ $c$  range ( $n = 1.015$ ) and 3.9 photoelectrons — in the 6–8 GeV/ $c$  range ( $n = 1.008$ ).

### 2.1. Description of aerogel measurements

The measurements were carried out at AANL (Yerevan). The transmittance of the aerogel was measured using an OCEAN-ART 402 spectrophotometer. The operational range covered wavelengths from the ultraviolet to the visible region (200–1025 nm).

The measurement procedure consisted of three steps:

1. *Initial measurement* (performed with the light source switched on, without the sample): the spectrum of the incident light as a function of wavelength was recorded.
2. *Dark current measurement* (performed with the light source switched off for the diaphragm in the light path closed): this step was used to evaluate and subsequently subtract the contribution of the instrument's internal noise from the data.
3. *Transmittance measurement* (performed with the light source switched on and the sample placed between the input and output optical fibers).

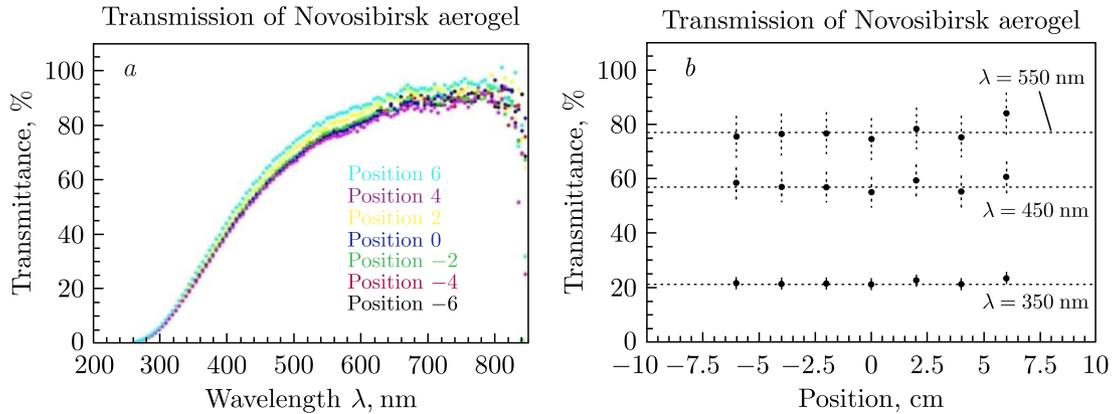
Based on the processing of the data obtained from these three measurements, the instrument provided the effective light transmittance as a function of wavelength in the range of 200–1000 nm.

2.2. Obtained results

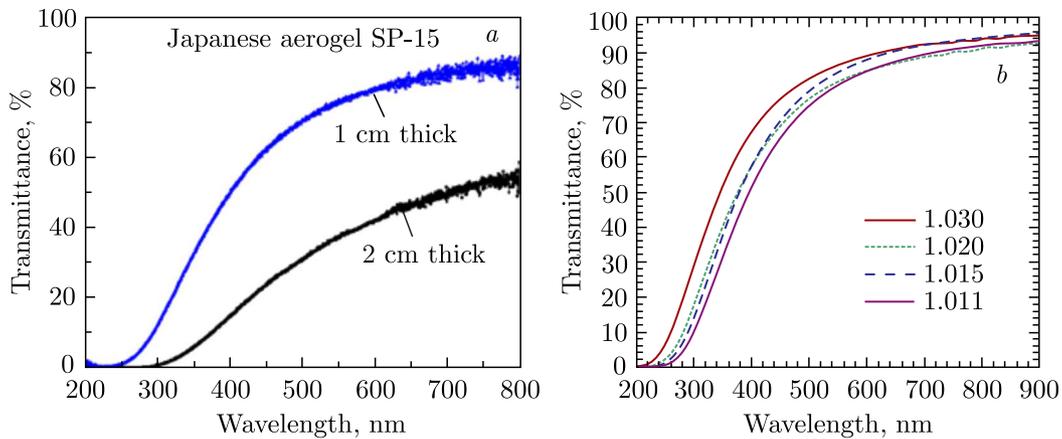
Transparency measurements were carried out for aerogels produced in Japan and the Russian Federation. Figure 2, *a* shows the transparency as a function of wavelength for different positions on the surface of a 3 cm thick aerogel sample (at the center and at offsets of  $\pm 2$ ,  $\pm 4$  and  $\pm 6$  cm from it). The BINP (Novosibirsk) aerogel has a refractive index of 1.030. Figure 2, *b* presents the transmittance dependence of the aerogel on the coordinate for three wavelengths, as a function of the sample surface position. From the data obtained, we can conclude that the sample is homogeneous.

In Figure 3, *a*, the transmittance dependence on wavelength is shown for aerogel samples with thicknesses of 2 and 1 cm. The refractive index of this sample is 1.015, produced in Japan. In Figure 3, *b*, the transparency dependence on wavelength is presented for aerogels with different refractive indices, measured in 2014. These data are included for comparison to assess the stability of aerogel transparency over extended time periods.

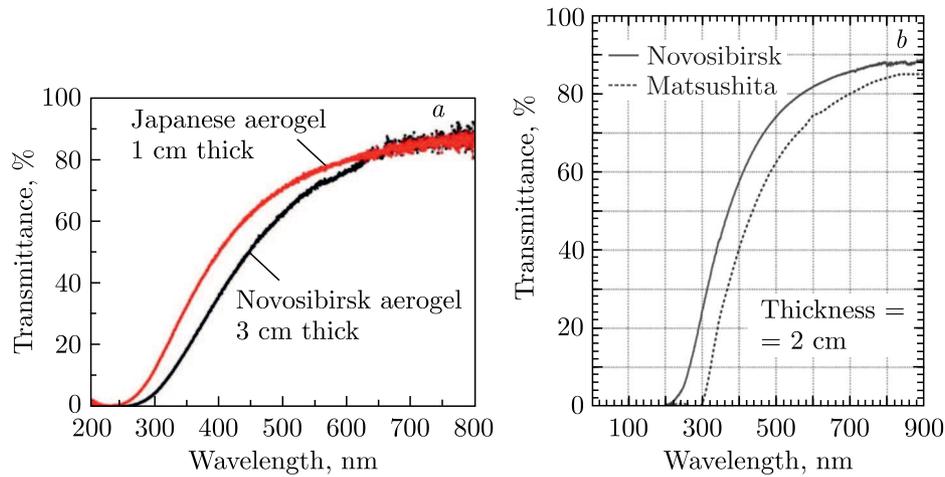
In Figure 3, *b*, the blue dashed line corresponding to a refractive index of 1.015 represents the aerogel sample measured by us. The refractive indices of the aerogel samples were taken from the manufacturer’s specifications [9].



**Figure 2.** *a*) Transmittance as a function of wavelength for a 3 cm thick aerogel; *b*) transmittance of the aerogel as a function of position for different wavelengths.



**Figure 3.** *a*) Transmittance dependence on wavelength for aerogel samples with thicknesses of 2 and 1 cm; *b*) transmittance dependence on wavelength for aerogels with different refractive indices, measured in 2014.



**Figure 4.** *a*) Transmittance as a function of wavelength for aerogels produced in Novosibirsk and by Matsushita, with thicknesses of 3 and 1 cm, respectively; *b*) transmittance as a function of wavelength for Novosibirsk and Matsushita aerogels with a thickness of 2 cm, measured in 2002.

Considering the negative effect of time (10 years or more) and storage under non-ideal conditions, we can conclude that the results are quite close to each other.

Transmittance as a function of wavelength for aerogels produced in Novosibirsk and by Matsushita, with thicknesses of 3 and 1 cm, respectively, is shown in Figure 4, *a*, while Figure 4, *b* demonstrates transmittance as a function of wavelength for Novosibirsk and Matsushita aerogels with a thickness of 2 cm, measured in 2002.

Within the accuracy of the available measurements and taking into account differences in experimental conditions, no significant degradation of the transparency of the Novosibirsk aerogel is observed over the considered time interval.

### 3. Summary

The paper presents the results of studies on the optical properties of aerogel samples intended for the SPD experiment at the NICA accelerator complex, which is being constructed at the Joint Institute for Nuclear Research in Russia.

The measurements of the optical transmittance of aerogel samples were carried out at AANL (Yerevan Physics Institute). Longitudinal transmittance measurements were performed for two different samples. The results showed that the transmittance of aerogel produced in Novosibirsk does not significantly deteriorate over time (approximately one year). Our measurements further demonstrated that the optical characteristics of the Novosibirsk aerogel samples are homogeneous.

For data processing and analysis, the OriginPro 8.5 and ROOT software packages were used. The obtained results were compared with similar measurements in order to assess the consistency and accuracy of the outcomes.

### Acknowledgements

We thank H. Mkrtchyan and V. Tadevosyan for assistance and technical support at various stages of the work. We are especially grateful to A. Barnyakov for provided samples of aerogel material produced at BINP.

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