A Method for Monitoring Inherent Optical Parameters at Underwater Neutrino Telescopes Sites

V.A.Balkanov[1], I.A.Belolapticov[7], L.B.Bezrukov[1], N.M.Budnev[2], A.G.Chensky[2], I.A.Danilchenko[1], Zh.-A.M.Djilkibaev[1], A.A.Doroshenko[1], S.V.Fialkovsky[4], O.N.Gaponenko[1], T.I.Gress[2], A.M.Klabukov[1], A.I.Klimov[6], S.I.Klimushin[1], A.P.Koshechkin[1], E.V.Kuznecov[1], V.F.Kulepov[4], L.A.Kuzmichev[3], S.L.Lovcov[2], B.K.Lubsandorzhiev[1], M.B.Milenin[4], R.R.Mirgazov[2], N.I.Moseiko[3], E.A.Osipova[3], Panfilov[1], Yu.V.Parfenov[2], A.A.Pavlov[2], E.N.Pliskovsky[1], P.G.Pohil[1], E.G.Popova[3], V.Yu.Rubzov[2], I.A.Sokalsky[1], Ch.Spiering[8], O.Streicher[8], B.A.Tarashansky[2], T.Thon[8], R.Wischnewski[8], I.V.Yashin[3]

[1] Institute for Nuclear Research, Moscow, Russia
[2] Irkutsk State University, Irkuts, Russia
[3] Skobeltsyn Institute of Nuclear Physics, Moscow, Russia
[4] Nizhni Novgorod State Technical University , Nizhni Novgorod,Russia
[5] St.Peterburg State Technical University, St.Peterburg,Russia
[6] Kurchatov Institute, Moscow, Russia
[7] Institute for Nuclear Research,Dubna,Russia
[8] DESY-Zeuthen, Zeuthen, Germany

Abstract

A method of measurement of the inherent optical parameters (IOP) of water: the absorption length , the scattering length and the scattering function is presented. The method is suitable for continuous monitoring of IOP in neighbourhood of underwater neutrino telescopes, because it is possible to absolutely calibrate a device "in situ".

Propagation of light in optical media is determined by two basic phenomena: absorption and scattering. Both processes are completely described by the following inherent optical parameters: absorption coefficient κ or absorption length $\lambda_{abs} = 1/\kappa$, scattering coefficient σ or scattering length $\lambda_{scat} = 1/\sigma$, and scattering function $\chi(\Theta)$.

For correct reconstruction of events in deep under water neutrino detectors one has to measure these parameters with an accuracy of a few percents, but typical values for λ_{abs} in the window of maximum transparency are about 20 - 50 m for clearest natural reservoirs. The determination of such values meets considerable problems. Measurements of λ_{scat} and $\chi(\Theta)$ are accompanied by additional difficulties because scattering in natural water is strongly forward peaked. Scattering in water by angles about one degree and less is mixed with different effects in used devices. At the same time, scattering by small angles is very important for the analysis of data from underwater detectors.

As a rule, devices with fixed short base length are used for invitro as well for insitu measurements of inherent optical parameters. The main difficulty for this type of instrument is their calibration. This problem becomes critical for long-term monitoring of optical water parameters at the site of Neutrino Telescopes.

Bauer et al (Bauer1971) suggested to use an isotropic light source and a similar receiver in a device for measurement of κ. It allows to change the base of an instrument "in situ" and by the way to get the absolute value of an absorption coefficient. A possibility to change the base length of a device is extremely useful for stationary installed apparates and allows to get κ with accuracy 1%. In (Bezrukov 1990) this result was confirmed by Monte-Carlo method for water at the site of the Baikal Neutrino Telescope.

This idea was used in the devices described in (Bezrukov 1990) and (Tarashansky 1995). The last device has an isotropic light source which is moved by a step motor up to distance 15 m from the receiver. Also the device has a narrow angle receiver for measuring of σ and $\chi(\Theta)$. The method of measurement and some of the results obtained by the device are published in (Tarashansky 1994), (Tarashansky 1996), (Budnev 1998). Unfortunately, the accuracy of reconstruction of σ in this method is about 10% for $\sigma R \sim 0.1$, where R is the distance between source of light and receiver and the error increases with increasing σR.

To improve measurements of the scattering coefficient we have designed and tested another method. The idea of the method is clear from Fig.1. There are two "kinds" of photons which come from the isotropic source S to the detector D with diameter $a \ll R$, where R is the distance between source and receiver. One part of photons reaching detector are not scattered, let us call them "direct" photons, and other photons are scattered. The total number of photons is $N_t = N_0\ exp(-\kappa\ R)$, the number of "direct" photons is $N_d = N_0\ exp(-\epsilon\ R)$ where $\epsilon = \kappa + \sigma$ and the number of "scattered" photons is $N_s = N_t - N_d$. Putting a screen at a distance $r \ll R$ from the source one can measure N_s. From results of alternate done measuring of N_s and N_t, the value of σ can be determinated:

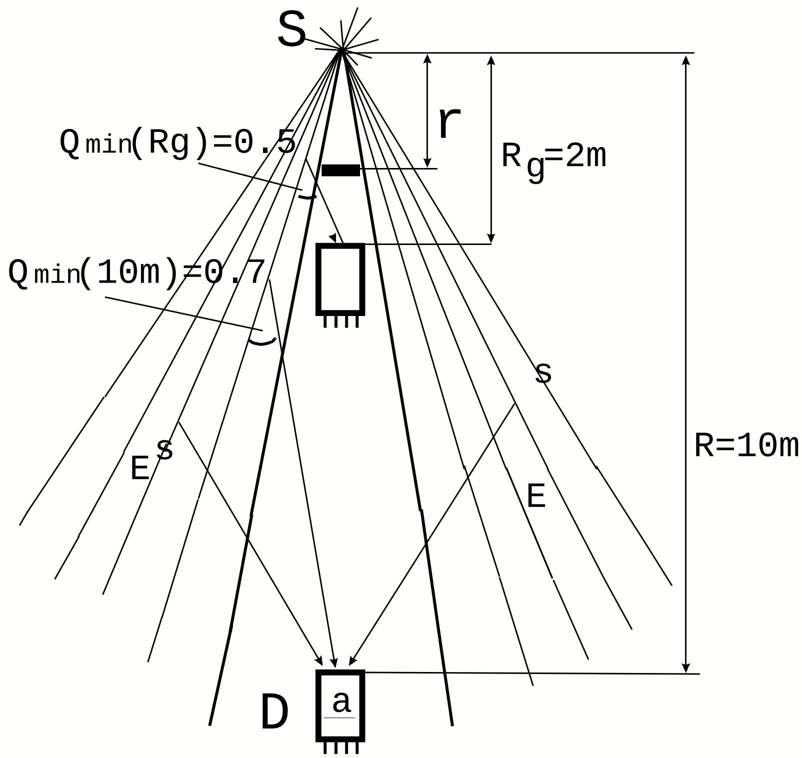

Figure 1: Scattering coefficient mathurement method

$$\sigma = -\frac{ln(1 - N_s/N_t)}{R}. \quad (1)$$

In principle, by this way of geometrical approach it is possible to get σ on angles larger then $\Theta_{min} = a/R$ with an accuracy about 1%, if the shadow of the screen completely coincidences with the receiver. But, still other reasons for additional experimental errors exist. The main one is the diffraction of photons on the screen, the second problem is the adjustment of the screen. Using special methods of suppression of the diffraction and optimizing distances R and r, it is possible obtain the experimental accuracy for σ of about a few percent.

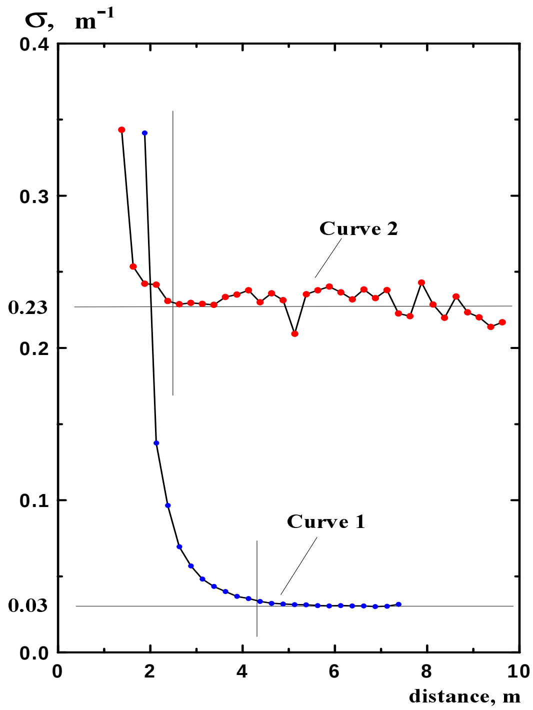

Figure 2: σ, computed according to (1), as a function of distance. Curve 1 - 05.04.98, depth - 250m, curve 2 - 15.03.99, depth - 4m

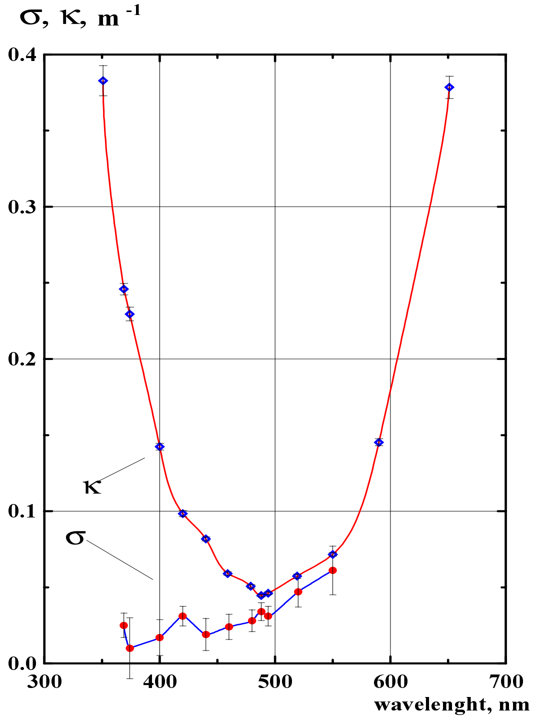

Figure 3: The absorption and scattering coefficients. Baikal, NT-200 site, 850m depth, 6 may 1997

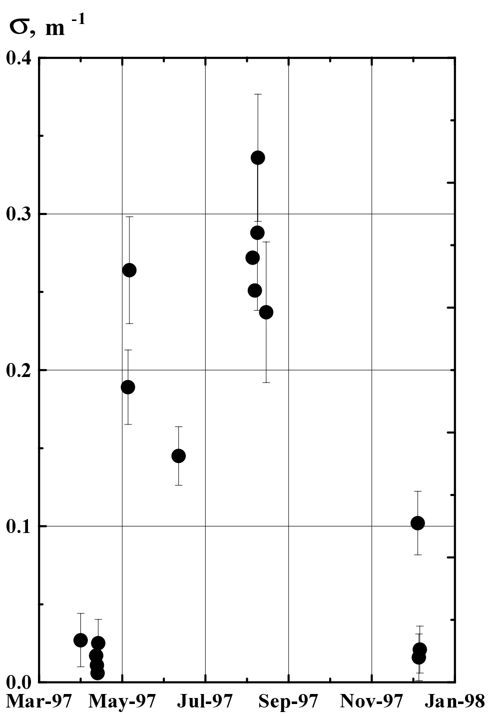

Figure 4: The variation of the scattering coefficient. Lake Baikal, 850m depth, 1997y

Fig.2 (curve 1) shows the result of calculation of σ according (??) from experimental data obtained at 05.04.98 at a depth of 250 m. Geometrical size of shadow from the screen (situated at the distance $r = 20\ cm$ from source) is equal with the size of the receiver at distance $R_g = 240\ cm$. So, up to R_g, the contribution of "direct" photons in N_s dominates. From R_g up to $R = 440\ cm$ some of the "direct" photons are detected due to diffraction on the screen. The right value of $\sigma = 0.03\ m^{-1}$ one gets from $R_\sigma = 440\ cm$ in this case. When the scattering length is very small (curve 2 on Fig.2 - 15.03.99, 4 m depth, $\sigma = 0.23 m^{-1}$) contribution of diffraction is negligible and $R_g \sim R_\sigma$. If one moves the detector from $R = R_g$ up to 10 m, angle Θ_{min} changes in our device from 0.5 up to 0.7 degree only, so, as a rule, we get flat curves on Fig.2 at $R \geq R_\sigma$. Changing r or R, one can get an information about the scattering function $\chi(\Theta)$. For example, we estimated the asymmetry coefficient of scattering function as $K \sim 30$ at 1200 m depth, using additionally data with a large screen.

The spectral dependence of σ in Baikal water is weak, compared with the spectral dependence of κ (Fig.3). We didn't observed variations of $\kappa(480\ nm)$ above 20% around an average value of $\kappa = 0.045\ m^{-1}$ at the NT-200 site, but variations of $\sigma(480\ nm)$ around an average value of $\sigma = 0.03\ m^{-1}$ may be more large. Extremely high variations of σ were observed in 1997 (Fig.4). It was also in that year, that an extraordinary large production of seaweed was observed.

This work was supported by the RFFI grant 97-05-96466.

References

Bauer, D., Brun-Cottan, J.C. & Saliot, A. 1971. Cah. Oceanogr. V.23. N.9. P. 841-858.
Bezrukov, L.B. et al. 1990. Oceanology of the Akademy of Science of the USSR. V.30. N.6. P.1022
Budnev, N.M. et al. 1998. Proc. of Workshop "Simulation and analysis methods of cube kilometer Neutrino detectors" Zeuthen, July 1998.
Tarashansky, B.A., Gaponenko, O.N. & Dobrynin V.I. 1994. Atmos. Oceanic Optics. V.7. P.819.
Tarashansky, B.A., Mirgazov, R.R. & Pocheikin, K.A. 1995. Atmos. Oceanic Optics. V.9. P.677.
Gaponenko O.N., Mirgazov R.R., Tarashansky B.A. 1996. Atmos. Oceanic Optics. V.9. P.677.