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THE EFFECT OF WAVELENGTH SHIFTERS ON WATER CHERENKOV DETECTORS

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We report the results of a test showing that concentrations of ≈2 mg/l of wavelength shifter in water give almost the maximum efficiency of detection without losing the directionality of Cherenkov light.

In recent years several experiments have been planned to measure the proton lifetime and, among those under construction, some detectors [1–3] use large amounts of water as a source of protons and Cherenkov light (CL) for detection of p-decay products. The dynamical interpretation of the events and the vertex reconstruction are the main problems in water Cherenkov detectors; these problems can be solved by measuring with good accuracy the energy and direction of p-decay products. In such a case, one can discriminate between real and background events, the main source of the latter being the interactions induced by atmospheric neutrinos deep underground.

In addition, such detectors can be used as well to observe neutrinos from point cosmic sources, both through the $\tilde{\nu}_e + p$ capture reaction and through the $\nu_e + e^-$ elastic scattering reaction. Since the last reaction roughly maintains the direction of the incoming ν_e flux, it is also important in this case to determine the e^- direction in order to correlate any event with a possible cosmic source.

Usually, the efficiency of detection is improved by adding a wavelength shifter (WS) in water, which absorbs the ultraviolet CL and re-emits it in the blue region of the spectrum, at wavelengths where photocathodes are more sensitive. However, the re-emitted light is isotropically distributed and does not maintain the original direction, when the WS is added in the usual concentration of about 11 mg/l of water [4,5].

We report here the results of a test whose purpose was to establish the optimal concentration of WS in water for which the efficiency of detection is maximum without losing the information about the direction of the incoming charged particles given by CL. We used in our test different concentrations of amino G, that is $NH_2C_{10}H_5(SO_3H)SO_3Na$, which is the most common WS used in water Cherenkov detectors.

Fig. 1 shows our experimental apparatus; it consists of a parallellepiped with two legs looking down-

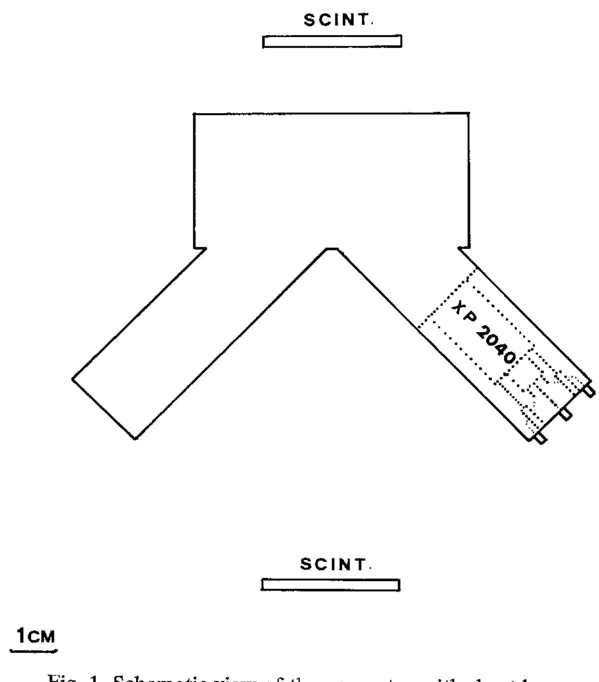

Fig. 1. Schematic view of the apparatus with short legs.

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wards at an angle of ~45°, i.e. nearly the Cherenkov angle in water. The legs are 25 or 60 cm long, ending with 2 Philips XP2040 photomultipliers. The internal surfaces of the apparatus are painted black and it is filled with deionized water, with a conductivity of 2.1 μS.

Muons from cosmic radiation are the source of CL, since two plastic scintillators, with an area of 30 × 30 cm^2, are set above and under the apparatus, making it a telescope to detect vertical cosmic ray muons. The triggering system was chosen in order to record any event giving a pulse in both plastic scintillators and in both photomultipliers, i.e. the telescope works on a 4-fold coincidence. With such a telescope, the measured muon flux was $(24.2 \pm 0.9)\ \mu$/min, while the number of random coincidences was quite negligible within the coincidence time 4×10^{-8} s. The anodic pulses from the two photomultipliers were summed together and then recorded on a multichannel spectroscope.

For both lengths of legs we measured the efficiency of detection of CL for different concentrations of WS; then we turned the appratus upside down and repeated the same measurements. In such a way, when the detector's legs are downwards, it is sensitive to both CL and isotropically diffused light from WS; on the other hand, when the detector's legs are upwards it is sensitive only to diffused light from WS. Thus, we made four runs of measurements with different appratus geometry i.e., downward short legs (DSL), downward long legs (DLL), upward short legs (USL) and upward long legs (ULL).

In order to have 2 large number of muons, each measurement had a duration ranging from 8 to 16 h and, during that time, we measured the mean number of photoelectrons per muon for the different WS concentrations. These latter values were obtained by calibrating the multichannel spectra with a Monte Carlo simulation, which gives the detection threshold and the number of photoelectrons per channel. The simulation was computed for pure deionized water, by choosing two random points, uniformly distributed over the plastic scintillators, that give a random muon track inside the apparatus; in our Monte Carlo simulation we assumed, as is usually done, that 250 CL photons were emitted per cm of path length, and the total number of photoelectrons generated by 10 000 muons crossing the apparatus was derived. Photons were supposed to be emitted randomly at directions lying on the Cherenkov cone and the photocathode quantum efficiency was supposed to have the constant value 0.1, so that the probability that a photon reaching the photocathodes extracts photoelectrons was computed from a Poisson distribution with mean 0.1.

As a result of the Monte Carlo simulation we obtained that the apparatus with short legs has a sensitivity of 1.0 photoelectron per channel, while for the long legs apparatus the sensitivity is 1.6 photoelectrons per channel. By mean's of this calibration, we can derive the mean number of photoelectrons per muon in each run. Table 1 gives the results for the

Table 1
Intensity, gain and residual directionality of Cherenkov light for different concentrations of wavelength shifter.

WS (mg/l)	Intensity (photoelectrons/muon)		*G*	RD	Intensity (photoelectrons/muon)		*G*	RD
	DSL	USL			DLL	ULL		
0.0	51.0				16.4			
0.5					18.2	11.5	1.11	0.41
1.0		37.0			18.8	12.7	1.15	0.37
1.5					19.1	13.6	1.17	0.34
2.0	60.5	39.5	1.19	0.41	19.4	14.5	1.19	0.30
4.0	61.0	41.5	1.20	0.38	19.7	16.1	1.20	0.22
6.0	61.0	42.5	1.20	0.36	19.7	16.4	1.20	0.20
8.0	61.0	43.0	1.20	0.35	19.7	16.4	1.20	0.20
10	61.0	43.0	1.20	0.35	19.7	16.4	1.20	0.20
12	60.5	43.0	1.19	0.34	19.7	16.4	1.20	0.20
14	61.0	43.0	1.20	0.35	19.7	16.4	1.20	0.20
50					19.4	17.0	1.19	0.15
100					19.4	17.0	1.19	0.15

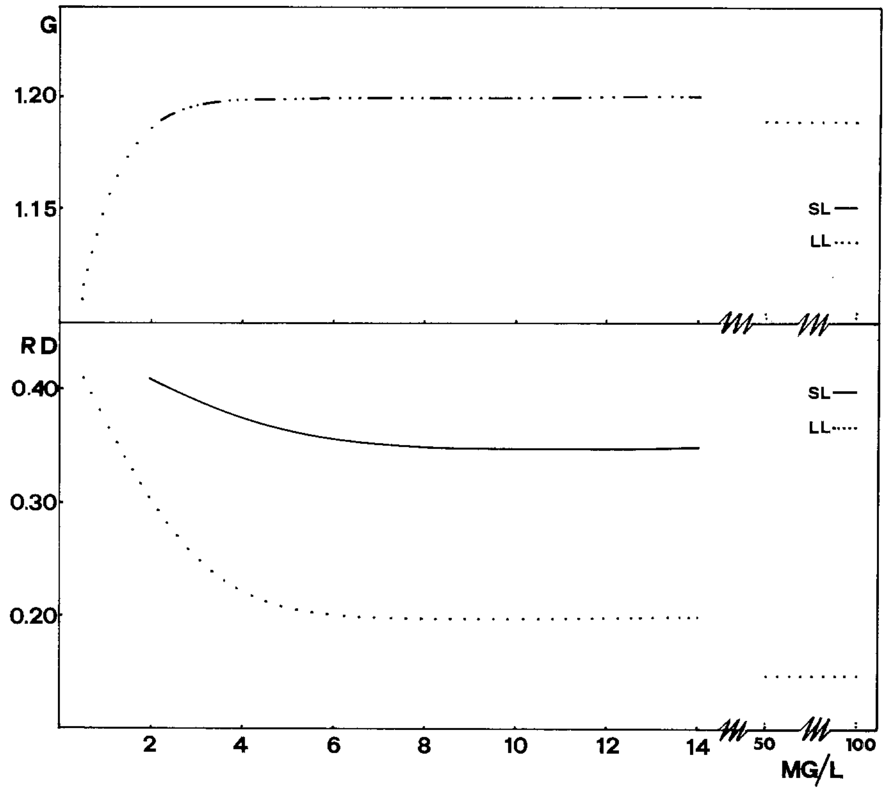

Fig. 2. Gain and residual directionality of Cherenkov light for different concentrations of wavelength shifter.

different runs as a function of WS concentration. In the same table we report the gain G of the detection efficiency and the residual directionality RD of CL.

The gain G has been defined as the ratio of the number of photoelectrons for a given WS concentration to the same number in pure water. The residual directionality has been defined as the ratio $RD = I/I_0$, where I is the CL intensity at a given WS concentration (obtained as the difference between the number of photoelectrons in the downward legs apparatus and the same number in the upward legs apparatus), and I_0 is the CL intensity in pure water. Fig. 2 shows the dependence of gain and residual directionality on WS concentration.

From our results, one can conclude that WS concentrations of less than ~2 mg/l of pure water, i.e. much smaller concentrations than usually used, are enough to give almost the maximum efficiency of detection without losing the CL directionality, which is the main information required to reconstruct topologically any event in water Cherenkov detectors.

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