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A STANDARD TRANSPARENCY-METER

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THE METHOD of measuring *in situ* the transparency of sea water to electric light by means of a selenium photo-element was introduced by HANS PETTERSSON in 1934 (2). In the transparency-meter constructed by him a small electric lamp behind a hemispherical lens gives a slightly divergent beam. This is sent out into the sea water through a plate-glass window, is reflected back against a mirror 100 cm distant from the window and impinges on the photo-element through a second window. Keeping the lamp-current constant, the photo-current gives a measure of the transparency of the 2 metres of sea water through which the light passes. Transparency-meters based on the same principle but with alterations as to the distance between the lamp and the photo-element have been constructed by others (3, 5, 6, 7). For limnological work it is generally sufficient with a distance of 1 m only, and then the mirror can preferably be avoided, the photo-element being separated from the lamp and placed in a case 1 m distant from the lamp case. During cruises with the »Skagerak» at different seasons in the seas surrounding Sweden the original transparency-meter has been frequently used, also when provided with colour filters (SCHOTT filters R G 1, V G 9 and B G 12) for measuring the transparency to three different parts of the lamp spectrum.

The selective extinction of light by sea water is generally studied by laboratory analysis which, by filtering the sample, offers the possibility of determining the part of extinction due to suspensoids. As the water samples collected from different depths as a rule cannot be investigated on board, but must be preserved for days or even for weeks, a preservative must be added. CLARKE and JAMES (1) have carried out laboratory analysis of the selective extinction of light in preserved samples of sea water collected at coastal and off-shore stations in the North Atlantic. They found that the preservative used affects the organic matter in the sea water and causes an increased absorption. This fact obviously demonstrates the necessity of field measurements.

The transparency-measurements hitherto made *in situ* mainly aimed at studying the variations in transparency with depth which are largely due to the presence of suspended organic particles, organic detritus or living plankton organisms, and they did not yield any values of the true extinction of sea water. However, it is an old desideratum to standardise the transparency-meter so that the extinction can be directly determined in order to make measurements with apparatus of different types and in different waters comparable *inter se*. In preference to the laboratory method, with which the laborious collection of water samples reduces the number of tests of the extinction, the direct method has the advantage of allowing for measurement of the continous alteration of the transparency with the depth so that the micro-stratification, occurring even in off-shore waters in great depths, for instance in the Baltic, can be detected. Besides it is not difficult to provide the transparency-meter with an arrangement for introducing colour filters automatically in front of the lamp in order to obtain the transparency to different spectral ranges.

After all, the method *in situ*, at least when employed in coastal waters, is to be preferred to the laboratory method though the latter, as mentioned above, admits of separating the effect of scattering due to suspensoids. However, it is probable that a combination of measurements of transparency and measurements of the extinction of submarine daylight might give information about the amount of scattering particles present in the water. This problem will be attacked in the near future.

SAUBERER (3, 4) has recommended a more frequent use of the Pettersson transparency-meter when fitted for spectral investigation. Pointing out that the transparency values obtained with the aid of the transparency-meter, when the photo-current produced in air is used as a standard, are strongly dependent on the optical equipment, he suggests that this should be made of a unitary type (4). However, it seems to me that it would be simpler to standardise the transparency-meters by employing a laboratory method. This presupposes that the optics can be adjusted so that the standardisation remains permanent and can be reproduced also when exchanging the lamp. In the following an attempt is described to standardise a transparency-meter by means of extinction measurements carried out with the aid of a Pulfrich photometer.

The transparency-meter is the original Pettersson apparatus with some recent technical modifications which may be set out here. The light source is a lamp of 4 volts and 4 watts with a rectangular filament of 1×1 mm. It can be centred to the optical axis of the hemispherical lens L (Fig. 1) by the three screws S_1, and can be moved parallel to the axis by the screw S_2. The whole tube containing the lamp and the lens can easily be taken out and then replaced and fixed in exactly the same position as before. The adjustment is performed so that the light-beam produced in air has a diameter at the mirror of about 10 cm, so that the active surface of the photo-element P

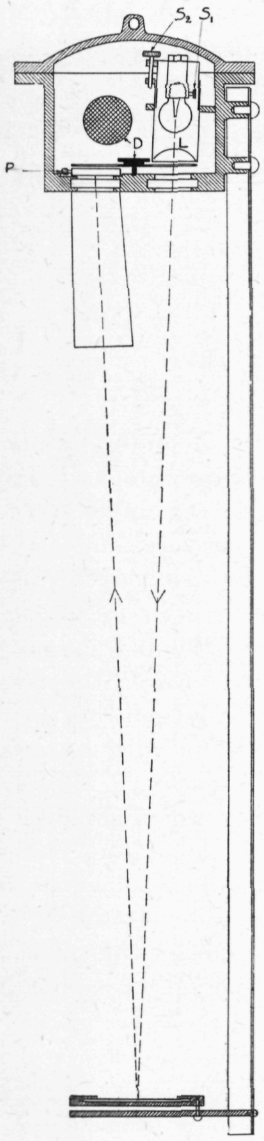

Fig. 1.

receives the whole diffuse image of the filament. This has the advantage that the contraction of the beam in water is of little account as about the same amount of energy from the lamp reaches the photo-element when readings are taken in air as in optically pure water.

The radiation of the lamp, its current being regulated by a resistance, is kept constant with the aid of a control photo-element (not visible in Fig. 1) placed 8 cm from the lamp and provided with a 2 mm blue filter B G 12, as the blue part of the lamp-spectrum is most sensitive to variations of the lamp-current. The light from the filament impinges on the control element through a hole in the lamp tube which is arranged so that the light spot just covers the active surface of the control element. Both photoelements used in the apparatus are selected among a great number of samples for their high sensitivity and small fatigue effect. The control element is connected with an A E G luxmeter, the element P with a light-spot galvanometer (sensitivity about $2 \, . \, 10^{-8}$ ampères per scale-unit). When readings are taken in air, the windows and the mirror being well cleaned, a certain deflection on the luxmeter always corresponds to a certain deflection on the galvanometer, *i. e.* when the photo-current, read on the luxmeter, by regulating the resistance is adjusted to a definite scale-point, the galvanometer is always to show the same deflection. At an exchange of lamps the new lamp is centred so that the beam, sent out through the window, gives a circular spot concentric to the mirror after which the mirror is slightly adjusted so that the image of the filament falls on the photo-element P. By means of the screw S_2 the lamp is moved towards the lens till the light beam just covers the control element and the desired correspondence between the two galvanometers is established.

Fig. 1 also shows an electromagnetic filter-changing device D which permits the introduction of three colour filters in succession, 2 mm R G 1, 2 mm V G 9 and 2 mm B G 12, and a screen in front of the lamp. The device, which requires 12 volts, is operated from ship-board. The entire device with the electromagnet and the filter disk can be placed in or withdrawn from the case as a unit when the lamp-tube is off.

The case always contains a dessiccator when the instrument is lowered into the water in order to avoid moisture on the windows. In a horizontal position the transparency-meter can measure the transparency within a water layer only some 5 cm thick. The corrections for submarine daylight to be deducted from the deflection, read at each depth, are found by introducing the opaque screen in front of the lamp.

The standardisation was performed in the following way. The water to be investigated was poured into an earthenware cylinder of such a height that the transparency-meter could be immersed in a vertical position. The air bubbles gathered below the windows were removed by means of a pipett. With some different lamp-currents, the luxmeter pointing at 30, 40 and 50 scale-units respectively, the deflection on the galvanometer was read. Between each change of the water in the cylinder the readings in air were checked. Using distilled water and adding rather turbid sea water taken directly from the fjord it was possible to prepare a number of water samples differing in transparency from very clear to very opaque. A sample of the water used in the cylinder was immediately placed in the Pulfrich tube, and its spectral extinction determined. The glass absorption tubes are exactly 1 m in length. It was worked with a 50 % aperture in the photometer in order to reduce the slight disturbing influence from light reflected against the inside of the tube. For comparison double-

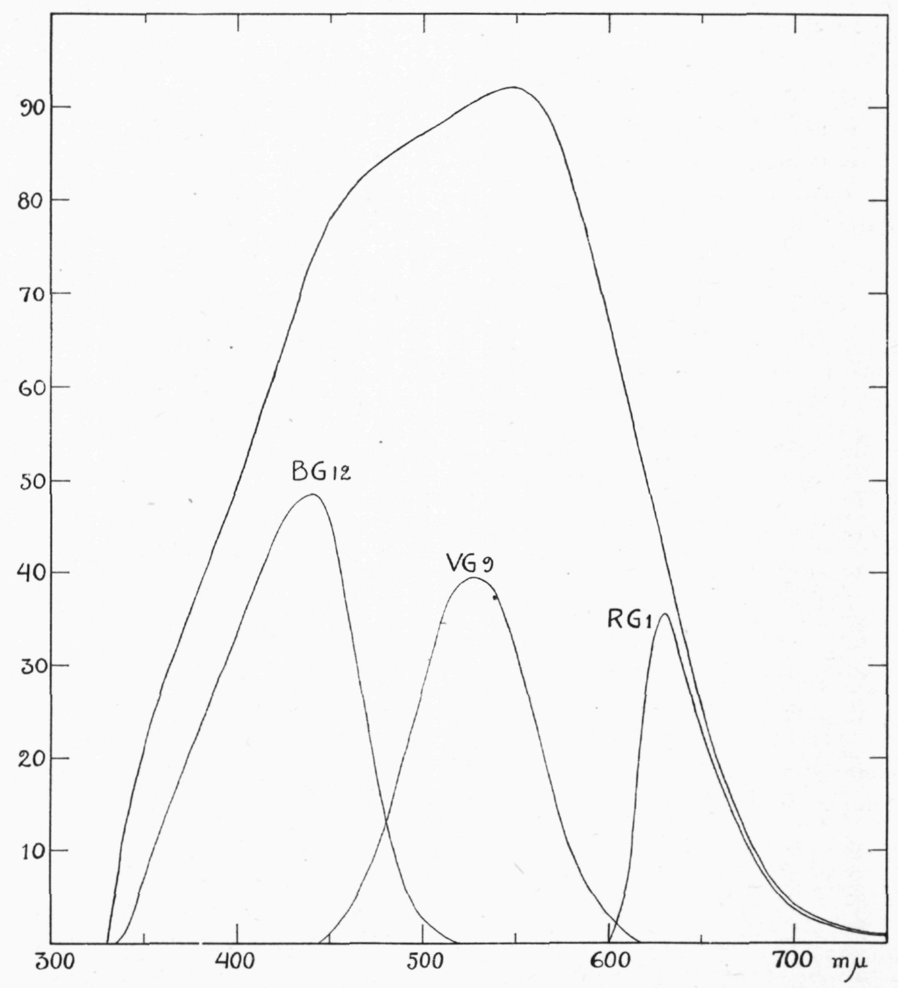

Fig. 2. The spectral sensitivity of the photo-element, and with filters.

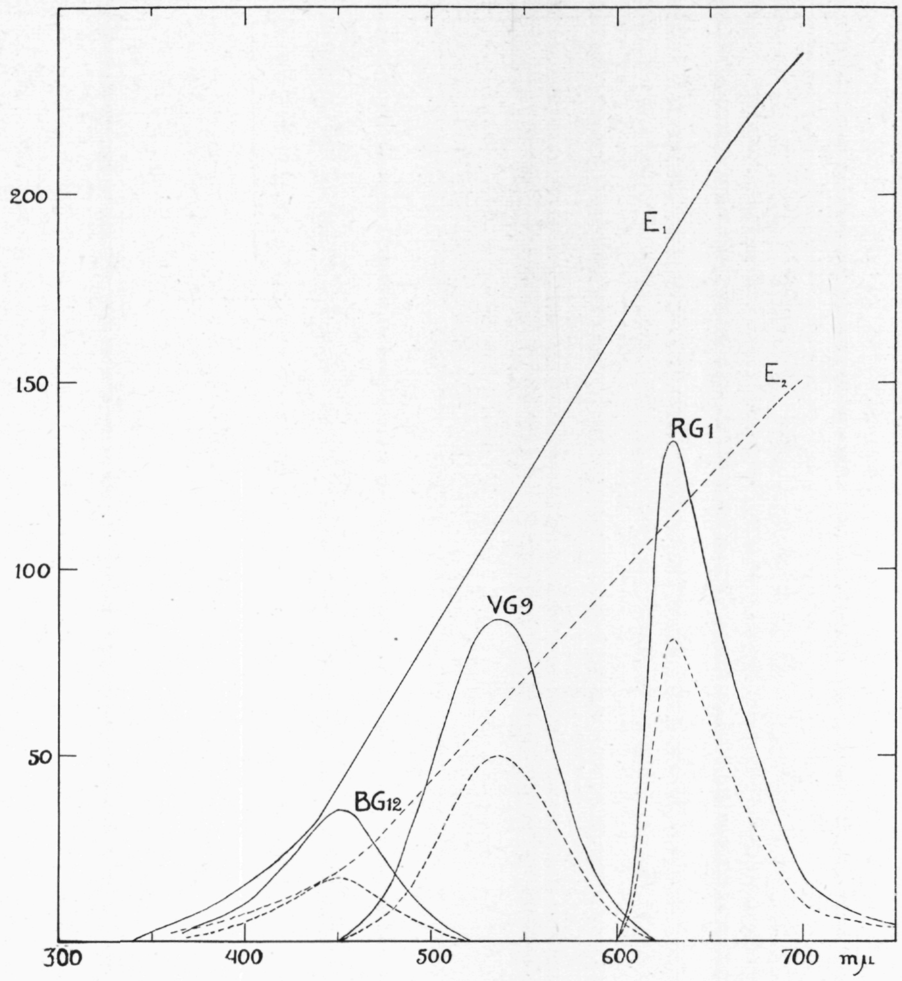

Fig. 3. The spectral energy distribution of the lamp light for 1.114 amp. (curve E_1, control value 50) and for 1.034 amp. (curve E_2, control value 25).

Tab. 1. The relation in percent between deflection in sea water and deflection in air for different control values.

Control	R G 1	V G 9	B G 12
30			24.3
40	20.3	34.2	25.0
50	20.3	34.2	24.5

distilled water was used. Distilled water was redistilled and run into a Pyrex glass container which is not likely to affect the transparency (1). Tests with the whole set of colour filters were run immediately after placing the double-distilled water and the water to be investigated in the tubes. It was found that the extinction in blue of the sample slightly increases after standing in the glass tubes for some hours.

Fig. 2 shows the sensitivity curves of the photo-element *P* alone, and with the three filters R G 1, V G 9 and B G 12, for an equal-energy spectrum. In the curves the spectral transmission of the two windows and the selective reflection against the mirror are included. The spectral sensitivity of the photo-element was obtained from our own measurements, whereas the transmission values of the filters were given by the makers.

The spectral energy distribution for the lamp light was found by means of colour filters, and is plotted in Fig. 3 for two lamp-currents, corresponding to control values of 25 and 50 scale-units respectively. The filter curves (on a relative scale) for each radiation are also given in Fig. 3. As the lamp spectrum is very deficient towards the blue end, the blue-filter curve is considerably diminished and shifted towards longer wavelengths, as compared with that for the corresponding equal-energy curve. However, it is seen from Fig. 3 that the centres of gravity of the three response curves for the lamp remain practically unshifted when the lamp emission rises to twice its value. This is also clear from Table 1 showing that the relation between the deflection in water and that in air with the three filters, and expecially with the blue filter, for which the relation is most influenced by changing the lamp current, comes out practically constant when the control is varied from 30 to 50 scale-units.

Thus the relation between deflection in water and deflection in air remains unchanged by a considerably change of the lamp-current.

In practice this means that the lamp-current can be suited to the transparency of the sea water, using a higher current in opaque water than in clear water. A temporary overload on the lamp of sufficiently short duration so as not to damage the filament is sometimes advisable in order to obtain greater deflections, for instance when measuring the extinction in blue with a very opaque water.

The transparency-meter measures the transparency within three spectral blocks. The ranges (at a tenth of maximum height) and the centres of gravity of these are obtained from the filter curves in Fig. 3 and given in Tab. 2.

Tab. 2. The filters.

Filter	Range mμ	Centre of gravity mμ
R G 1	605—705	660
V G 9	470—600	535
B G 12	380—510	445

Owing to the tailing off of the R G 1 curve towards the infra-red its centre of gravity falls at 660 mμ *i. e.* 40 mμ from the maximum of the curve.

Instead of calculating with these average wavelengths only I have chosen the more exact way of evaluating for the whole spectrum the transmission values for 2 metres light-path from the Pulfrich measurements, using Clarke and James' extinction values for double-distilled water. The spectral transmission curve for 2 metres in the water sample is drawn, after which mean transmission values for the filters are evaluated. The clearest water used was ordinary distilled water. Naturally it could not be avoided that this sample was contaminated when the transparency-meter was lowered into it, and therefore the extinction found

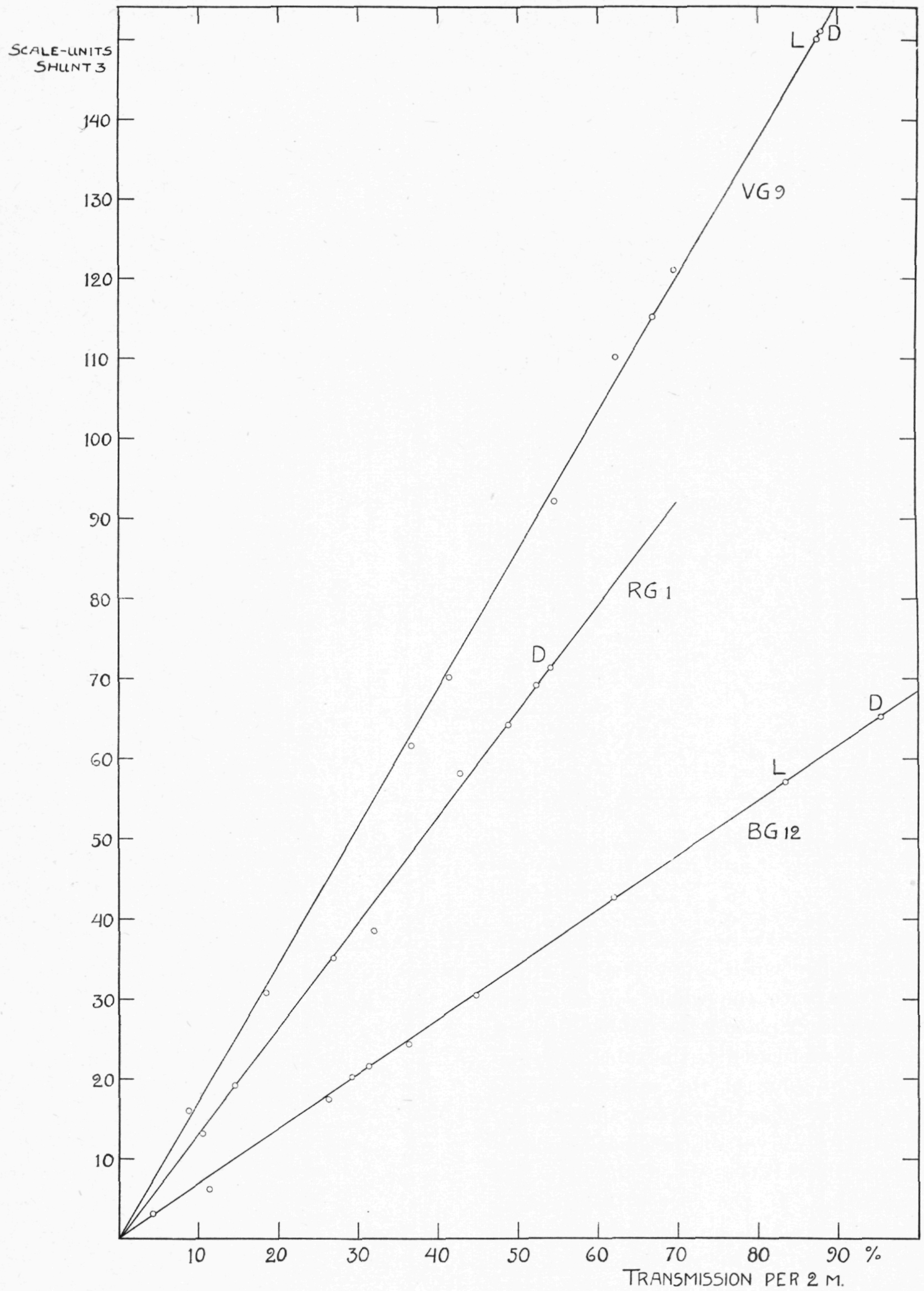

Fig. 4. Transmission values per 2 metres and deflection values. Control value: 40 scale-units

especially in blue, is considerably higher than that for double-distilled water.

In Table 3 the transmission values computed in this way are put together with the corresponding deflection values (scale-units with shunt 3 on the galvanometer). These deflections as well as the following refer to a control value of 40 scale-units. Most deflections are read with shunt 1 but are reduced to shunt 3 by division with 3.23. Within the actual illumination range the »curvature» error for the photo-element has been determined, and the corrections applied on the deflection values. In the graph, Fig. 4, the computed transmission values per 2 m are plotted against the deflection values. It is seen that the expected linearity is well established for all three filters. The points *D* on the lines refer to the calculated transmission values per 2 metres for double-distilled water according to CLARKE and JAMES, while the points *L* indicate the deflection in air. Table 4 shows values for the *D* and *L* points. Owing to the high extinction in red the point *L* for R G 1 lies outside the graph.

The straight lines in the graph represent the desired relation between transparency and deflection given by the transparency-meter. From this relation and using the *D* and *L* values we compute the conclusive standardisation data pre-

Tab. 3. Standardisation results. Control value: 40 scale-units.

Sample	R G 1		V G 9		B G 12	
	Scale-units sh 3	Transm. per 2 m %	Scale-units sh 3	Transm. per 2 m %	Scale-units sh 3	Transm. per 2 m %
3	69	52.3	121	69.5	24.2	36.4
4	64	48.7	110	62.1	20.1	29.2
5	19.1	14.5	30.7	18.5	6.0	11.3
6	58	42.7	115	66.8	42.5	62.0
7	(46.0)	(38.8)	92	54.7	30.3	44.8
8	38.4	32.0	70	41.5	21.5	31.4
9	35.0	26.9	61	36.7	17.2	26.2
10	13.1	10.5	15.9	8.8	3.1	4.2

sented in Table 5, u_w being deflection in water, u_a deflection in air.

Thus the relation u_w/u_a is essential for obtaining the transparency value. With V G 9 this ratio happens to coincide numerically with the transmission per 2 metres in relation to double-distilled water.

It is clear from this investigation that the standardisation of a transparency-meter is a fairly simple procedure provided its construction admits of keeping the optical properties unchanged by any renewal of lamps. The linearity of the curves in Fig. 4 testifies that in standardising a transparency-meter the determination with one sample of comparatively pure water is sufficient for all practical purposes, for instance with distilled water, the extinction of which may be easily determined by a laboratory method.

I am much indebted to Prof. Hans Pettersson for facilitating this investigation.

Tab. 4.

	D		*L*	
	Scale-units sh 3	Transmission per 2 m %	Scale-units sh 3	Transmission per 2 m %
R G 1	71.5	54.1	150	—
V G 9	151	87.8	150	87.2
B G 12	65.5	95.3	57.0	83.4

Tab. 5.

	R G 1 660 mμ	V G 9 535 mμ	B G 12 445 mμ
True transmission per m	$1.07\sqrt{\frac{u_w}{u_a}}$	$0.94\sqrt{\frac{u_w}{u_a}}$	$0.91\sqrt{\frac{u_w}{u_a}}$
Transmission per m in relation to double-distilled water	$1.46\sqrt{\frac{u_w}{u_a}}$	$1.00\sqrt{\frac{u_w}{u_a}}$	$0.93\sqrt{\frac{u_w}{u_a}}$

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