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# The Refractive Indices of Water and of Sea-Water

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# *The Refractive Indices of Water and of Sea-water.*

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1. *Method of Observation.*—Measurements of the refractive indices of water have been made by Fraunhofer, Gladstone, Van der Willigen, Dufet, Pulfrich, and many others. Those now offered were made by the new method previously described.*

2. *Instruments.*—In addition to the instrument used for measuring the refractive indices of fluorite quartz and calcite,† a larger goniometer has been employed, especially for determining the temperature-refraction coefficients and for the critical part of the work generally. This instrument has quartz objectives of 3 inches diameter and 27·5 inches focal length, and quartz-calcite objectives of 2·375 inches diameter and the same focal length, and it has a divided circle of 18 inches diameter. There are two micrometers with reading microscopes, one on each side of the circle. These micrometers are similar to that of the smaller goniometer before described,† and readings were taken in the same way. The hollow prism (by Hilger) used to contain the water has a clear aperture 1·675 inches by 2·375 inches, and is entirely of quartz. It can be used on either instrument (see Appendix).

3. *Temperature.*—A standard thermometer, interchangeable with the stopper, was kept with its bulb in the water during each measurement and, subject to the precautions for maintaining an approximate temperature of 15° C. before described,† readings were taken at the commencement and at the close of each measurement, and the mean taken. In no case did the variation between these exceed 1° C. By means of the temperature-refraction coefficients, which were found in both cases for three wave-lengths, the coefficients for the other wave-lengths were interpolated, and all the indices in the table corrected for a mean temperature of 15° C.

4. *Material.*—I am indebted to the kindness of Mr. W. R. Bousfield for the special examples of distilled water used. That for the experimental work on the variation of index due to impurities was supplied in a platinum bottle, that for the remainder of the work in a large bottle of special green glass, but little soluble. One cubic centimetre of this latter evaporated in a polished silver dish left a slight residue which was shown by subsequent experiment to have little effect on the index. For the specimen of sea-water

* 'Roy. Soc. Proc.,' Feb. 13, 1902. † *Loc. cit.*

I am indebted to Lieutenant E. R. G. Evans, R.N., who took it in blue water, 5 miles south of the Royal Sovereign Lighthouse (off the coast at Eastbourne). It was surface water and was collected in another large glass bottle of the same kind.

5. *Standard Wave-lengths.*—Rowland's have again been adopted whenever possible.

6. *Measure of Error.*—This is the same as already described.* The approximate estimate made from group deviations is as follows:—

*Water.*—There are 26 measurements in the table, in

| | | | | | | |
|---|---|---|---|---|---|---|
| 5 | of which $\alpha$ | = less than | $\frac{2}{3}''$ | corresponding value of | index | = 0·0000025 |
| 11 | „ | = „ | $1\frac{1}{3}''$ | „ | „ | = 0·0000050 |
| 8 | „ | = „ | $2\frac{2}{3}''$ | „ | „ | = 0·0000098 |
| 1 | „ | = more than | 2″·861 | „ | „ | = 0·0000098 |
| 1 | „ | = as much as | $5\frac{1}{2}''$ | „ | „ | = 0·0000202 |

*Sea-water.*—There are 12 measurements in the table, in

| | | | | | | |
|---|---|---|---|---|---|---|
| 5 | of which $\alpha$ | = less than | $\frac{2}{3}''$ | corresponding value of | index | = 0·0000025 |
| 5 | „ | = „ | $1\frac{1}{3}''$ | „ | „ | = 0·0000050 |
| 1 | „ | = „ | $2\frac{2}{3}''$ | „ | „ | = 0·0000098 |
| 1 | „ | = as much as | 2″·688 | „ | „ | = 0·0000103 |

Owing to the additional difficulties, especially with sea-water, the accuracy is not so great as with solid bodies; but these indices may be taken as correct to the fourth decimal place, and it is believed that in all cases the error does not exceed 0·000025, and in most is not more than 0·000015.

*Appendix.*—Special experimental work. In order to determine the disturbing effect due to the double refraction of the quartz plates forming the sides of the hollow prism, at the suggestion of Dr. Glazebrook a complete measurement was made on the large goniometer, and then, each plate having been rotated through 180° in its own plane, another complete measurement of index for the same wave-length (line E) was made. The results, reduced to 15° C., were as follows:—

| Plates normal. | Plates rotated through 180°. |
|---|---|
| 1·3356125 | 1·3356185 |

Want of parallelism in the faces of the plates was tested for by registering the position of the image of the slit (collimator and telescope being in line) without a prism, and then interposing the empty prism in its normal position and noting the effect. The difference of position of the image was not measurable.

To determine the extent and influence of impurities in solution, a specimen

* *Loc. cit.*

of ordinary distilled water, kept in an ordinary glass bottle, a cubic centimetre of which gave considerable deposit on evaporation, was measured.

Mean result, reduced to 15° C. = 1·3355798.

Table of Refractive Indices at 15° C.

| Wave-length. | Water. | Sea-water. |
|---|---|---|
| 7950·0 Rb ..... | 1·32855 | |
| 7682·45 $K_\alpha$(A′) ..... | 1·329183 | 1·335652 |
| 7065·59 He(B′) ..... | 1·330443 | 1·33689 |
| 6563·04 $H_\alpha$(C) ..... | 1·331562 | 1·338062 |
| 5893·17 Na(D) ..... | 1·333433 | 1·339959 |
| 5607·1 Pb(Λ) ..... | 1·334289* | 1·340938 |
| 5270·11 Fe(E) ..... | 1·335643 | 1·342298 |
| 4861·49 $H_\beta$(F) ..... | 1·337501 | 1·344260 |
| 4678·35 Cd ..... | 1·338515 | 1·345315 |
| 4340·66 $H_\gamma$(G′)..... | 1·340723 | 1·34763 |
| 3961·68 Al..... | 1·343959 | 1·350928† |
| 3610·66 Cd ..... | 1·347915 | |
| 3302·85 Zn ..... | 1·352699 | |
| 3034·21 Sn..... | 1·358337 | |
| 2748·68 Cd ..... | 1·36675 | 1·37494 |
| 2573·12 „ ..... | 1·37390 | |
| 2445·86 Ag′ ..... | 1·380979 | |
| 2312·95 Cd ..... | 1·389262 | |
| 2265·13 „ ..... | 1·39309 | 1·402880 |
| 2194·4 „ ..... | 1·39937 | Absorption begins |
| 2144·45 „ ..... | 1·40455 | Absorption |
| 2098·8 Zn ..... | 1·409702 | „ |
| 2062·0 „ ..... | 1·414543 | „ |
| 2024·2 „ ..... | 1·41996 | „ |
| 1988·1 Al ..... | 1·425663 | „ |
| 1933·5 „ ..... | 1·4361 | „ |
| 1852·2 „ ..... | Absorption | „ |

*Note.*—The number of figures in each index indicates the estimated freedom from errors of observation. The following interpolated indices are in all probability more correct for those referred to:—* 1·334294 † 1·35094.

A specimen of the special distilled water referred to, kept in a platinum bottle and prepared in platinum vessels, 1 c.c. of which, when evaporated in the silver dish, left a just perceptible residue, was then measured—

Result, reduced to 15° C. = 1·3356359.*

This specimen was then boiled and measured again—

Result, reduced to 15° C. = 1·3356338.

* There is a difference of reading for line E, resulting in 0·0000076 in the index between the two goniometers used, which it was difficult to account for. On testing the division of the two circles by readings from various zero points, I find that the large one stands the test almost up to the unit in the sixth place of decimals in the value of the index, while the smaller just begins to show discrepancy at five places: thus it is the smaller circle that is in fault. The experimental measurements here given were made on the large goniometer, but, for the sake of uniformity with previous measurements of index,

Finally, the same specimen was frequently agitated with air while standing for a week, and three measurements were then made—

Mean reduced to 15° C. = 1·3355777.

During the measurements of sea-water the prism was emptied and refilled for every complete measurement to prevent errors due to rise of density from evaporation and to the displacement of the sides by salt crystals.

Temperature Refraction Coefficients.

| Wave-length. | Water. | Sea-water. |
|---|---|---|
| 5893 (D)..... | −0 ·0000801 | −0 ·0000785 |
| 2748..... | — | −0 ·0000747 |
| 2265..... | — | (−0 ·0000758) |
| 2145..... | −0 ·0000724 | |
| 1988..... | −0 ·0000687 | |

all those given in the table have been made on the smaller instrument. But they agree well with other observers. The index for the mean D line in the table is 1·333433. This, brought to its value at 20° C. by use of the temperature coefficient, becomes 1·333032. Dufet ('Recueil de Données Numériques,' vol. 1, p. 83) gives the mean value of the measurements of this line at 20° C. by 29 observers as 1·33303.