A study on the vee block refractometer

Enrique J. Campitelli

Centro de Investigaciones Opticas
C.C. 124 (1900) La Plata, Argentina

Introduction:

The vee block (Hilger-Chance) refractometer[1,2] is to be preferred in the optical shop because of its good precision, because it measures the bulk and not the skin refractive index, and for the little work needed in the preparation of the sample. The latter is its most important feature.
The exiting angle D is a function of the block index n_V, and the sample index n. It is assumed the squareness of the angles marked in fig. 1.
For the ideal case, with all surfaces exactly made, the formula for the index is[3]:

$$n = [n_V^2 - \sin D\,(n_V^2 - \sin^2 D)^{1/2}]^{1/2} \qquad (1)$$

In this formula, if $n < n_V$, D is positive according to optical conventions. In practice, the sample is only fine ground, and the interface with the block is filled with an immersion liquid whose index approaches that of the sample. In this way the scattering is minimized.

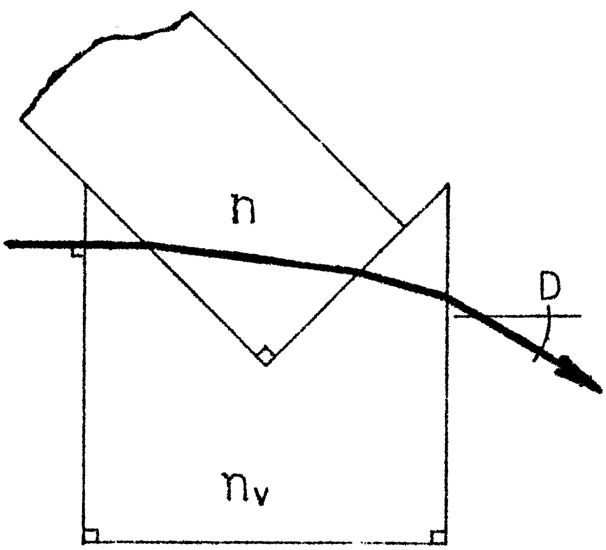

Fig. 1: Vee block refractometer. Schematic

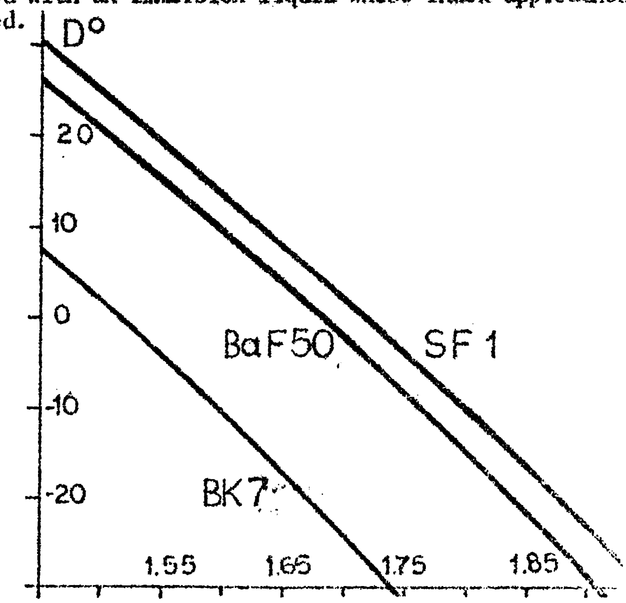

Fig. 2: D vs. n for a block of: BK7 (cheap), BaF50 (hard), and SF1

Optics:

The first question in the project of such refractometer is to select the glass for the block.
The available range in the refractive index (Eg: the Schott Catalog) lies from 1.45 to 1.95. If one attempts to cover it with only one block, its index must be such that the angles $|D|$ be a minimum, in order to measure them with precision. In addition, the glass should be, if possible, cheap and hard.
The glass SF1 makes the best compromise with regard to deviation. Its index, for sodium D light is n_V = 1.71715. It is near but not equal to the middle of the range. The extreme deviations are; for n = 1.95, D = -31.46° and for n = 1.45, D = 31.11°. In the analysis below, it is assumed n_V = 1.71715.

Next to be considered is the important question of the error due to the presentation of the sample.
The matching of liquid index ($n_L = n$) can be made first measuring $D = D_1$, with the gap filled only with liquid, then D_2 with liquid plus sample, and mixing liquids until $D_1 = D_2$. This may be time consuming, a slight mismatch may be tolerated. In a similar way, the angle S of the sample edge may not be exactly 90°. In the presence of these two errors, the resultant D, when introduced in formula (1) will yield a nominal value of n, say 'n'. The error of measurement is δn = 'n' - n.
It is easily seen that if $n = n_L$ or $S = 90°$, although $S \neq 90°$ or $n \neq n_L$, respectively, the error δn is zero because there is not an inhomogeneous wedge.
For a more complete analysis, it was constructed a numerical model of the refractometer. The deviation in ...

realistic model is found by tracing meridional rays through a system of 5 prisms in contact, the sequence of indices being: 1 , n_V , n_L , n , n_L , n_V , 1 . In this way, the wedges and index variations are taken into account. The formulae for ray tracing are much simpler than the standard ones, and follows from figures 3 and 4.

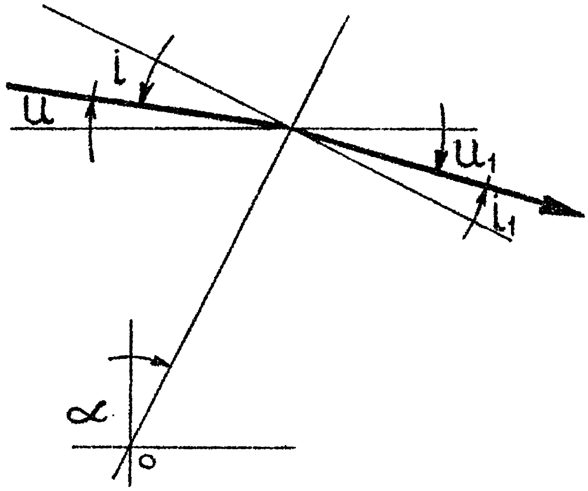

Fig. 3: Ray slope (all positive diagram).

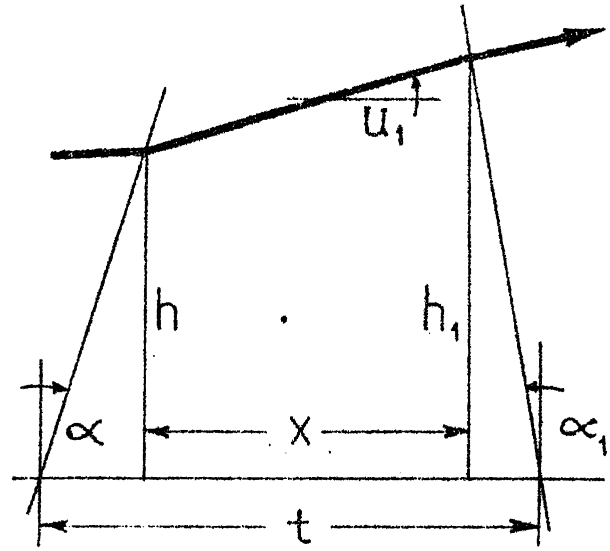

Fig. 4: Ray height.

From fig. 3: $\alpha = u + i = u_1 + i_1$ From this and Snell law, it follows:

$$u_1 = \alpha - \text{arc sin}\,[(n / n_1) \sin (\alpha - u)] \tag{2}$$

From fig. 4: $h_1 = h - x \tan u_1$; $x = t - h \tan \alpha + h_1 \tan \alpha_1$. From this, it follows:

$$h_1 = [h + \tan u_1 \, (h \tan \alpha - t)] / [1 + \tan u_1 \tan \alpha_1] \tag{3}$$

Equations (2) and (3) are recursive. Only (2) is needed to find D , and it was programmed in a small TI-59 calculator that runs the entire sequence at once. Eq. (3) is used later in finding the width and position of the beam.

The model enables many features to be studied, but to achieve some practical result, it was necesary to make additional assumptions (fig. 5).

1): The block is perfectly made (Angles $\alpha_1 = \alpha_6 = 0°$; $\alpha_2 = -45°$, $\alpha_5 = 45°$)

2): The sample lies supported by the left face of the vee. (Angle $\alpha_3 = \alpha_2 = -45°$)

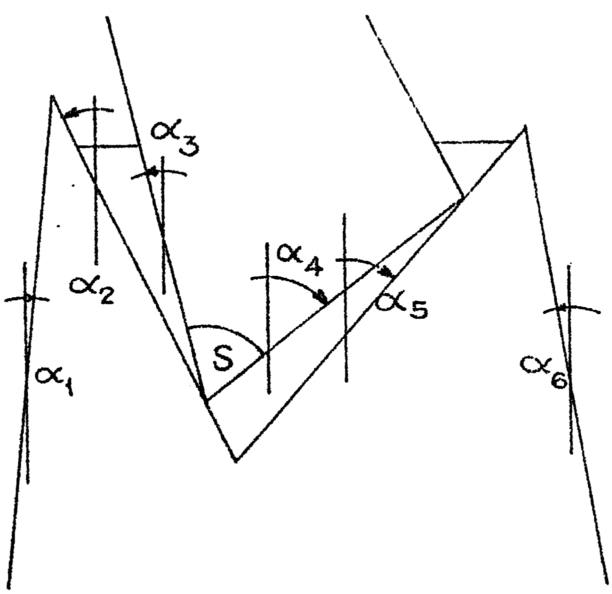

Fig. 5.

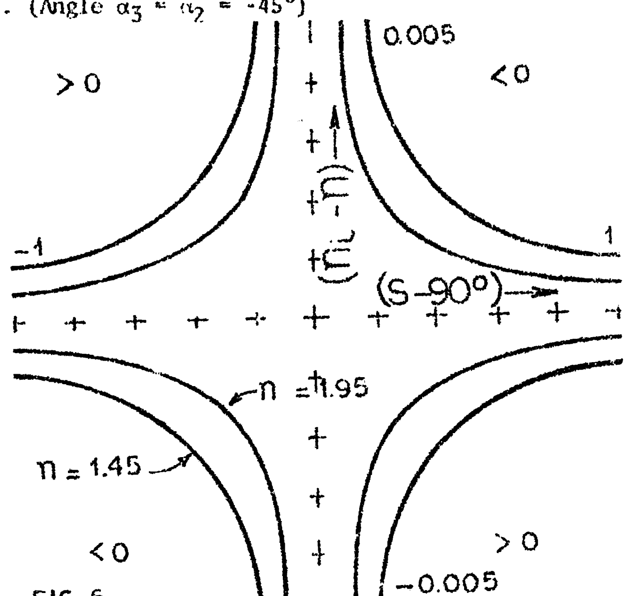

FIG. 6

Locus of $\delta n = \pm 10^{-5}$ for $n_V = 1.71715$

The angle S may be greater than or less than 90°. Taking these data as a basis, it was made a series of calculations of the error δn for reasonably small values of $(s - 90°)$ and $(n_L - n)$, and all the rang $1.45 \le n \le 1.95$. One way of displaying the results is plotting in a graph with $(s - 90°)$, $(n_L - n)$ as the locus of 'isoerror' curves, $\delta n = \pm K$, parametrized by the value of n (Fig. 6).
The curves are very nearly hyperbolas. On the first and third quadrant; ie, for $(S - 90°)$ and $(n_L - n)$ of the same sign, δn is negative. The higher the index, the smaller the tolerance.
Since in a problem like this, it is better a simple although approximate formula, an interpolation procedu was applied to the data. After averaging over the four quadrants, it was found a coefficient $A(n)$ in th equation:

$$\delta n = A(n)\ (n_L - n)\ (S - 90°)$$

Repeating the procedure for several values of n and taking the linear approximation for $A(n)$, the foll ing formula results:

$$\delta n = 10^{-2}\ (1.876 - 2.093\ n)\ (n_L - n)\ (S - 90°)$$

In the region of interest (ie: the graph), the values are found within ∿ 2% to those of the model, also in wavelengths F and C.

Mechanics:

Two features are to be presented:
1) The measurement of angles in terms of linear motion. 2) The autocollimation mode of operation.
The first one is based in the sine table device, well known in the mechanical shop.
The details are best seen in the drawing of fig. 8.
The glass block is at the same height than the steel block, so that a part of the mirror intercepts the b and the other is in contact with the cylinders.
The drawing shows them separately for clarity. The beams are drawn when measuring an index $n = 1.95$ (ful and $n = 1.45$ (dashed). The drawing of course does not show how all things are held together, nor the aut limator, that is supposed to lie at the right.
The autocollimator must have a vertical motion so that the center of the beam coincide with the optical ax Otherwise the reading of D depends on the focus position and there is an uncertainty due to the focal d In terms of the distance X and the radius R of the cylinders is:

$$\sin D = X / 2R$$

Considerations of precision and diffraction in the collimator lead to a scale of the instrument so that R is of the order of 25 mm. Other dimensions are proportional in the drawing.
The index n and its variation dn / dx as a function of X are plotted in fig. 7 for $R = 25$ mm. It i seen that $\Delta n \le 10^{-5}$ if $\Delta x = 1$ µm.
The screw needs calibration, but it may be cheaper than a precision divided circle. The geometrical relati ships are immune to backlash and wear, and the construction is simple.
A better solution could be to place two digital linear motion devices instead of the screw and resilient s and take the mean of the readings.

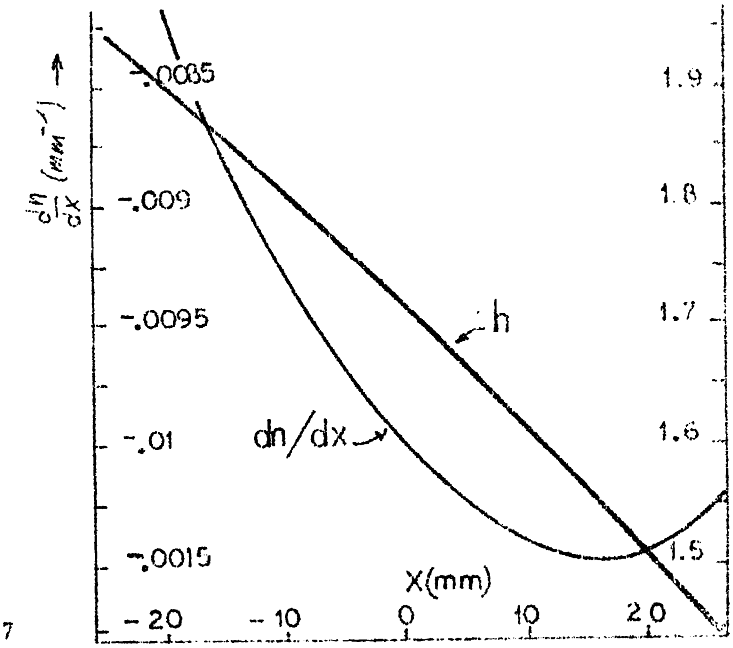

Fig. 7

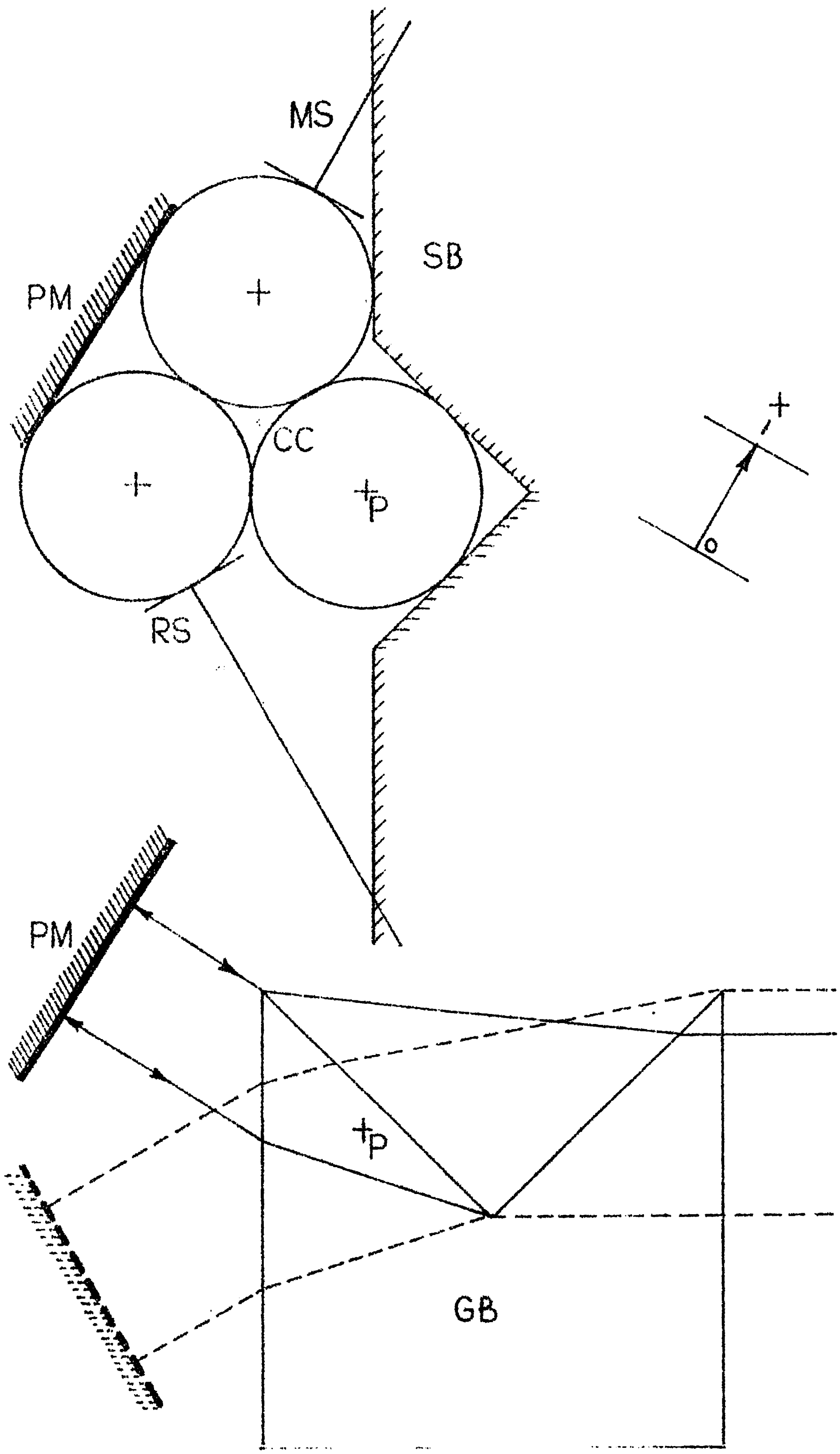

Fig. 8

MS: Micrometer screw

SB: Steel vee block

PM: Plane mirror

CC: Three calibrated cylinders

P: Pivot

RS: Resilient stop

GB: Glass vee block

References:

1. J.V. Hughes. J. Scientific Instruments 18, 234 (1941).

2. A.J. Werner. Applied Optics 7, 837 (1968).

3. J.C. Wyant. Optical Testing, pag.23. Optical Sciences Center, University of Arizona, June 1976.