Thermal focus drift of a glass lens, checked against published glass data

N-BK7 plano-convex lens, f = 100 mm at f/4, three wavelengths, −40 to +80 °C, two mount materials

The question

When the temperature of a lens changes, its glass index, its curvatures and the length of its mount all change, and the focus moves. This note checks the value etendue computes against the temperature coefficients the glass maker publishes and against the published first-order law of thermal defocus, applied without approximation to a thick N-BK7 lens. Over 18 cases, the computed focus drift stays within 0.255 µm of the reference.

The reference

The glass maker publishes the temperature coefficients of the index of its glasses, with the formula and constants behind them [1, 2]. The focus of a lens in a mount follows a first-order law [3], quoted here from [4]. For a plano-convex lens with its flat face towards the image, that law is exact at first order, so the reference adds no thin-lens approximation. Only the rounding of the datasheet limits it, to ±0.29 µm over 20 K.

1 The lens

Table 1. The lens of the study, as loaded in etendue. The image plane sits at the paraxial focus at 546.1 nm and 20 °C. Lens and mount start at the same temperature and change together.

PARAMETER	VALUE	PARAMETER	VALUE
Lens	Plano-convex, N-BK7	Radius of the curved face	51.872 mm
Centre thickness	4 mm	Focal length at 546.1 nm	100.000 mm
Entrance pupil	25 mm (f/4)	Lens to image plane	97.3662 mm
Wavelengths	1060.0, 546.1, 435.8 nm	Mount expansion, ULE / Al 6061	0.03 / 23.6·10⁻⁶/K

2 Focus drift against the reference

How far does the focus move when the lens warms by 20 K, and does etendue agree with the published law? With a mount that does not expand (ULE), the focus moves by a few micrometres, set by the glass alone. With an aluminium mount, the mount dominates and the image plane moves about 43 µm away from the focus. In both cases etendue stays within the ±0.30 µm that the rounding of the published data allows.

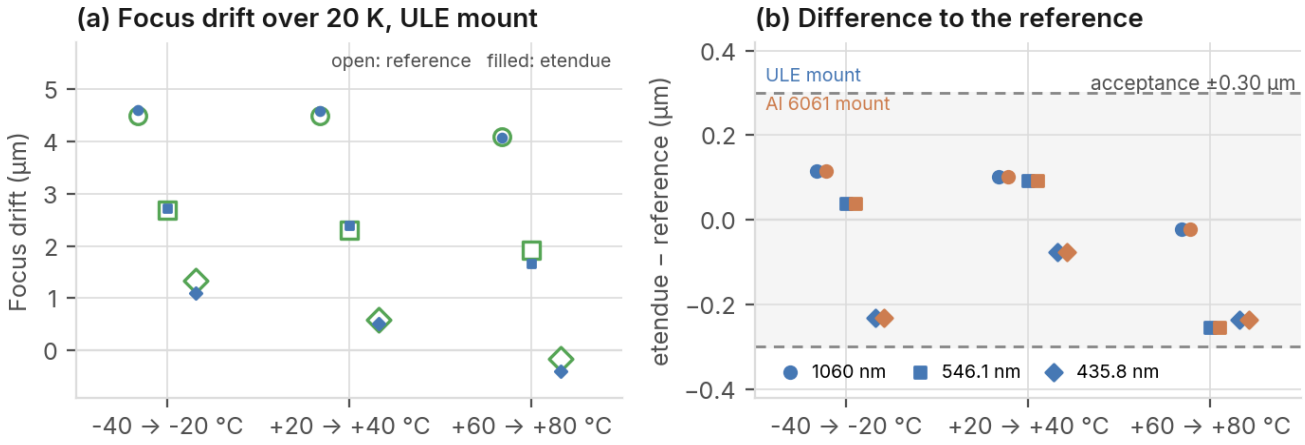


Figure 1. (a) Focus drift at the end of each 20 K interval, measured from the image plane, with the ULE mount: open markers are the reference, filled markers the value computed by etendue. (b) The difference for both mounts. The shaded band is the acceptance written before the measurement.

18/18
Focus-drift cases within ±0.30 µm of the reference. The largest difference is 0.255 µm.

9/9
Absolute dn/dT values of N-BK7 within ±0.05·10⁻⁶/K of the datasheet.

0.0 %
Difference of the default depth of focus to 2λN², at three wavelengths.

115/116
All criteria written before the measurement. The other is explained on page 2.

What was compared, and what differs

Eleven glasses for the index, one lens and two mounts for the focus, 116 values in all.

Table 2. Focus drift at the end of each 20 K interval (positive: beyond the image plane)

Interval	Wavelength	Ref., ULE (µm)	etendue, ULE (µm)	Ref., Al (µm)	etendue, Al (µm)	Difference (µm)
-40 → -20 °C	1060.0 nm	4.49	4.60	−41.4	−41.3	0.12
-40 → -20 °C	546.1 nm	2.69	2.72	−43.2	−43.2	0.04
-40 → -20 °C	435.8 nm	1.33	1.09	−44.6	−44.8	−0.23
+20 → +40 °C	1060.0 nm	4.49	4.59	−41.4	−41.3	0.10
+20 → +40 °C	546.1 nm	2.30	2.40	−43.6	−43.5	0.09
+20 → +40 °C	435.8 nm	0.59	0.51	−45.3	−45.4	−0.08
+60 → +80 °C	1060.0 nm	4.09	4.06	−41.8	−41.8	−0.02
+60 → +80 °C	546.1 nm	1.92	1.67	−44.0	−44.2	−0.25
+60 → +80 °C	435.8 nm	−0.16	−0.39	−46.1	−46.3	−0.24

Table 3. Mean dn/dT of N-BK7 over each interval (10^{-6}/K, datasheet rounded to 0.1)

INTERVAL	WAVELENGTH	REL., SHEET	REL., ETENDUE	ABS., SHEET	ABS., ETENDUE
-40/-20 °C	1060.0 nm	2.4	2.35	0.3	0.33
-40/-20 °C	546.1 nm	2.9	2.85	0.8	0.79
-40/-20 °C	435.8 nm	3.3	3.30	1.2	1.20
+20/+40 °C	1060.0 nm	2.4	2.36	1.1	1.06
+20/+40 °C	546.1 nm	3.0	2.95	1.6	1.62
+20/+40 °C	435.8 nm	3.5	3.48	2.1	2.13
+60/+80 °C	1060.0 nm	2.5	2.50	1.5	1.48
+60/+80 °C	546.1 nm	3.1	3.15	2.1	2.11
+60/+80 °C	435.8 nm	3.7	3.73	2.7	2.68

Table 4. Every criterion written before the measurement

COMPARED QUANTITY	WITHIN CRITERION
Lens as loaded (radii, thicknesses, focal length)	1/1
N-BK7 constants and index at 20 °C	11/11
N-BK7 dn/dT relative to air, 9 values	9/9
N-BK7 dn/dT absolute, 9 values	9/9
Relative dn/dT, 11 glasses × 3 wavelengths	32/33
Expansion coefficient, 11 glasses	11/11
Index n_e at 20 °C, 11 glasses (N-FK58 not judged)	10/10
Thermo-optic constant G, 11 glasses	11/11
Focus drift, ULE and aluminium mounts	18/18
Default depth of focus, $2\lambda N^2$	3/3
Total	115/116

Which wavelength stays fixed

The glass maker holds the vacuum wavelength fixed [1, eq. (3)]. etendue, like common lens-design programs, reads a wavelength as measured in air at the current temperature. The comparison therefore gives etendue the air wavelength of the same light at each temperature; it then reproduces the published formula to $0.0007 \cdot 10^{-6}$/K. At a fixed air wavelength the relative coefficient is higher by 0.007 to $0.21 \cdot 10^{-6}$/K; on the focus drift of Table 2 this accounts for 0.04 to 0.23 µm. Indices are compared at the spectral lines the sheets name, 546.074 and 435.8343 nm [5].

What stays outside the criteria

For N-FK51A at 435.8 nm, etendue differs from Table 1 by $-0.052 \cdot 10^{-6}$/K; the published formula with the constants of the datasheet gives −0.052, so the tabulated value does not follow from its own formula at the displayed precision.

Not judged

Table 2 of [1] prints n_d in place of n_e for N-FK58. Against the N-FK58 datasheet (n_e = 1.45720), etendue differs by $1.5 \cdot 10^{-6}$.

Domain of validity

−100 to +140 °C, 365 to 1014 nm; lens and mount at one uniform temperature, in air at 1 atm. Gradients and stress birefringence were not compared.

Conclusions

etendue computes the thermal focus drift of a lens in its mount within 0.255 µm of the published law, at three wavelengths and in three temperature ranges. Fed the same indices, the law and etendue agree to better than 10^{-10} µm. The one value outside the criteria is a table value that its own formula does not give.

References. [1] SCHOTT AG, TIE-19 Temperature Coefficient of the Refractive Index, August 2023, eq. (3)-(10), Tables 1 and 2. [2] SCHOTT AG, data sheet N-BK7, December 2023. [3] T. H. Jamieson, Thermal effects in optical systems, Optical Engineering 20(2), 156-160 (1981). [4] M. J. Riedl, Optical Design Fundamentals for Infrared Systems, SPIE Press, ch. 7, as reproduced in R. Irvin, OPTI 521 report, University of Arizona (2009), Table 1 and p. 2. [5] SCHOTT AG, TIE-29 Refractive Index and Dispersion, August 2023, Table 1.