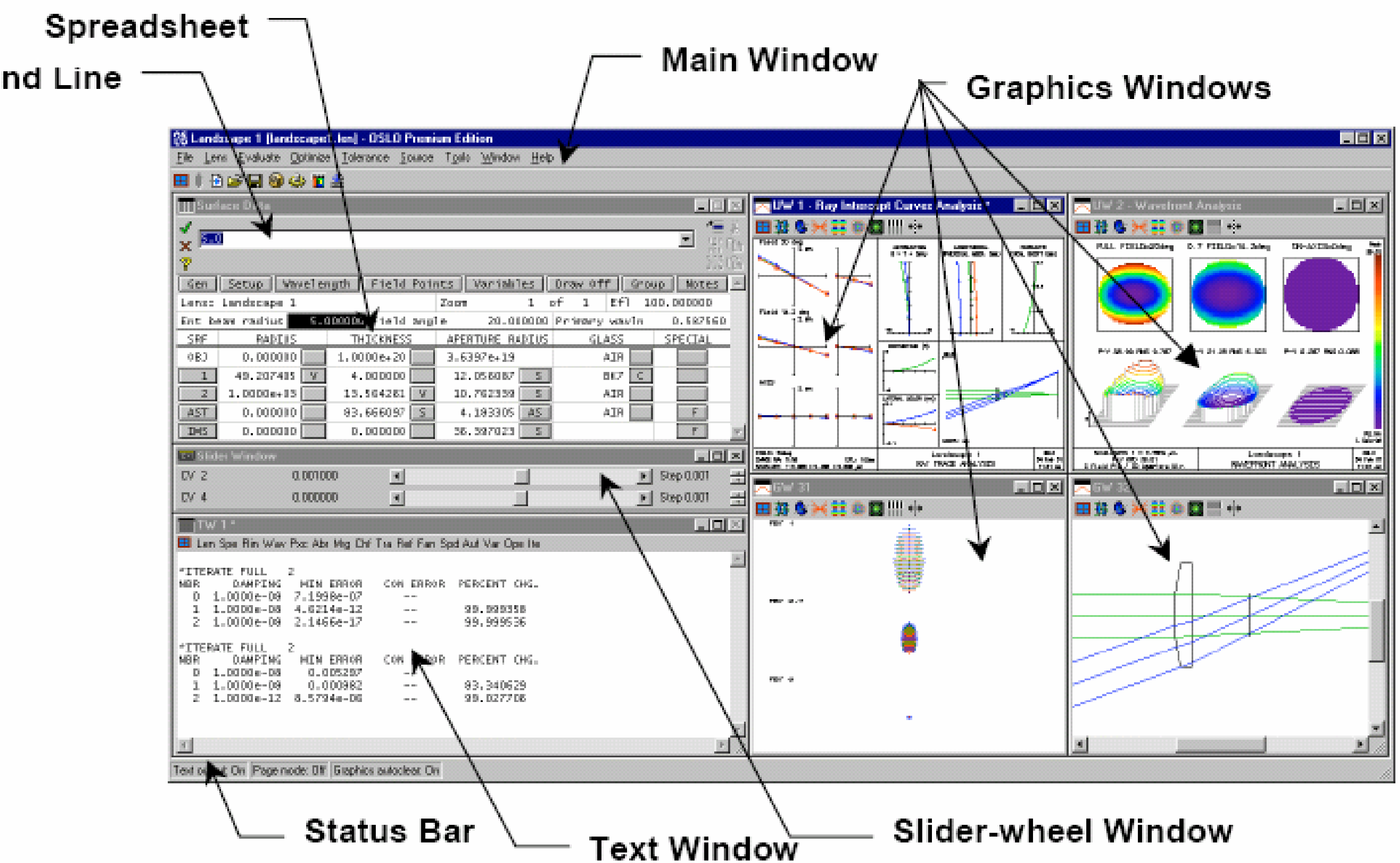
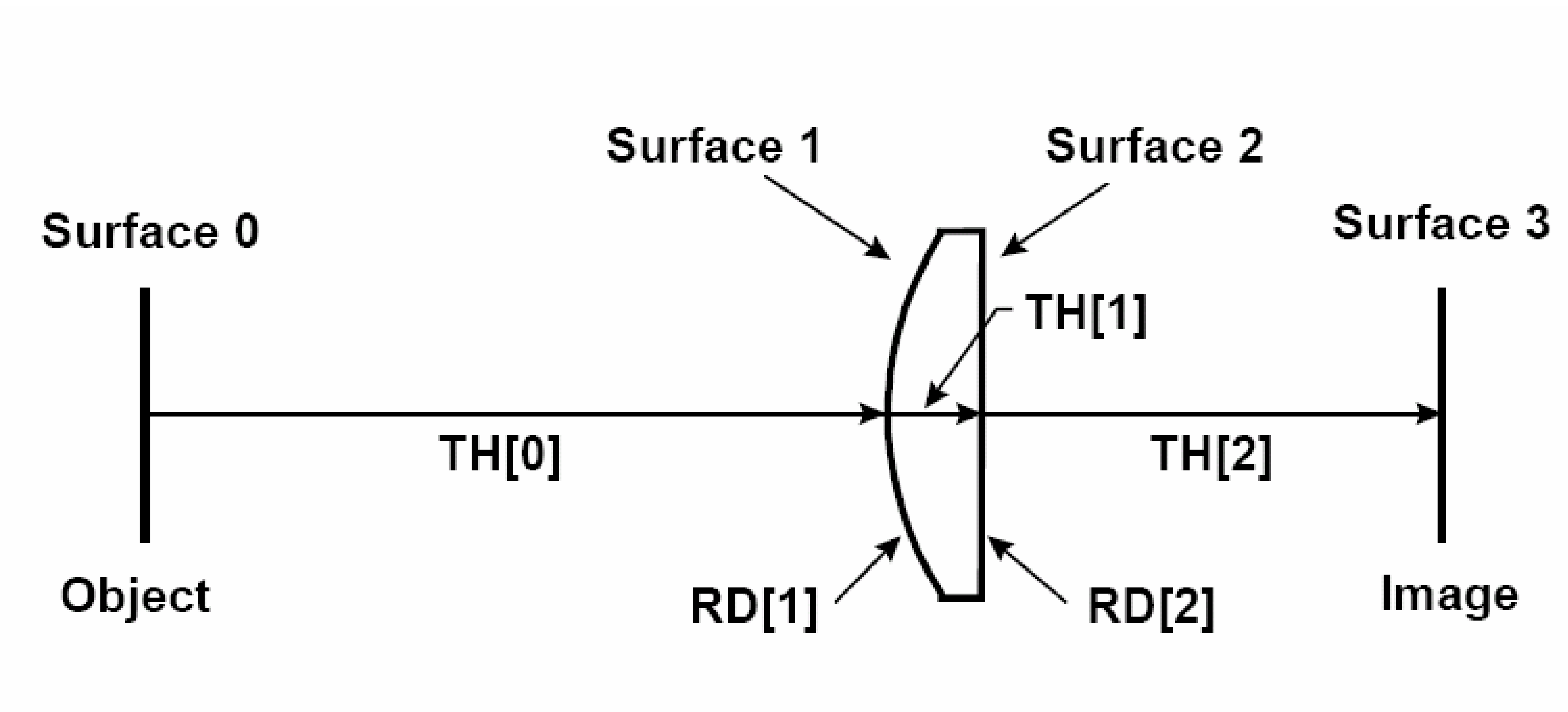
Introductory exercise for OSLO

A typical configuration of OSLO



Surface numbering



Sign conventions

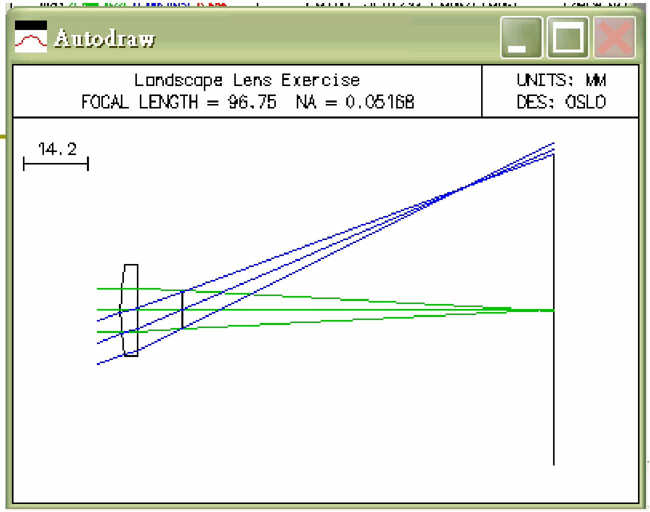
Sign conventions for centered systems

RADIUS OF CURVATURE	The radius of curvature, or curvature of a surface is positive if the center of curvature lies to the right of the surface.
THICKNESS	The thickness separating two surfaces is positive if the next surface lies to the right of the current surface; otherwise it is negative.
REFRACTIVE INDEX	OSLO expects all refractive indices to be provided with positive signs. Reflecting surfaces are specified explicitly by the designation, **rfl**.

Steps in the exercise

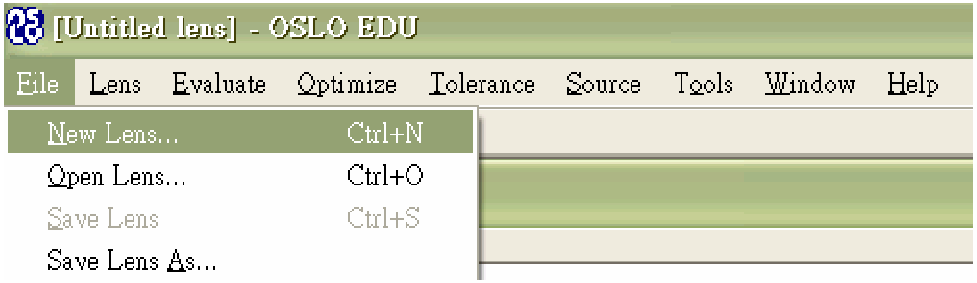
- **Lens entry** - Enter a convex-plano lens with a displaced aperture stop behind the lens.
- **Lens Drawing** - Set up the lens drawing conditions to show desired ray trajectories.
- **Optimization** - Optimize the lens so it has no coma, a focal length of 100, and covers a field of ±20 degrees at an aperture of f/10.
- • **Slider-wheel design** - Attach sliders to parameters so you can analyze trade-offs.

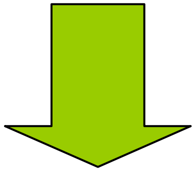
Lens entry, 1

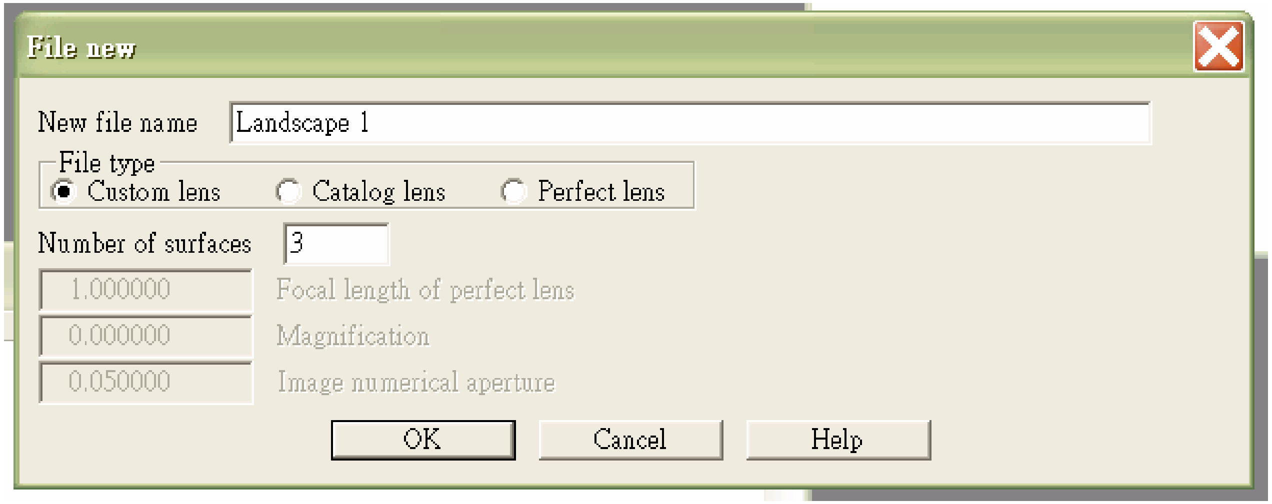


- beam radius = 5 mm
- field angle = 20 degree
- Convex-plano lens
  - Radius of surface 1= 50 mm
  - Radius of surface 2= 0 mm **(∞)**
  - Thickness=4 mm
  - Material= BK7
- Initial position of aperture stop=10 mm after the surface 2 of the convex-plano lens

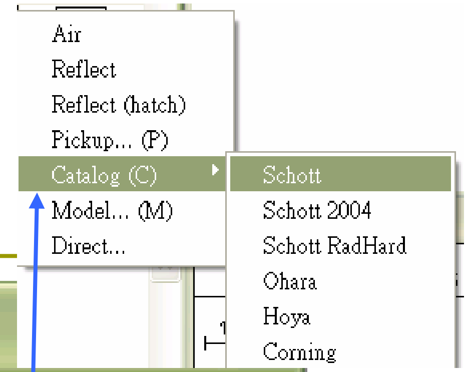
Lens entry, 2

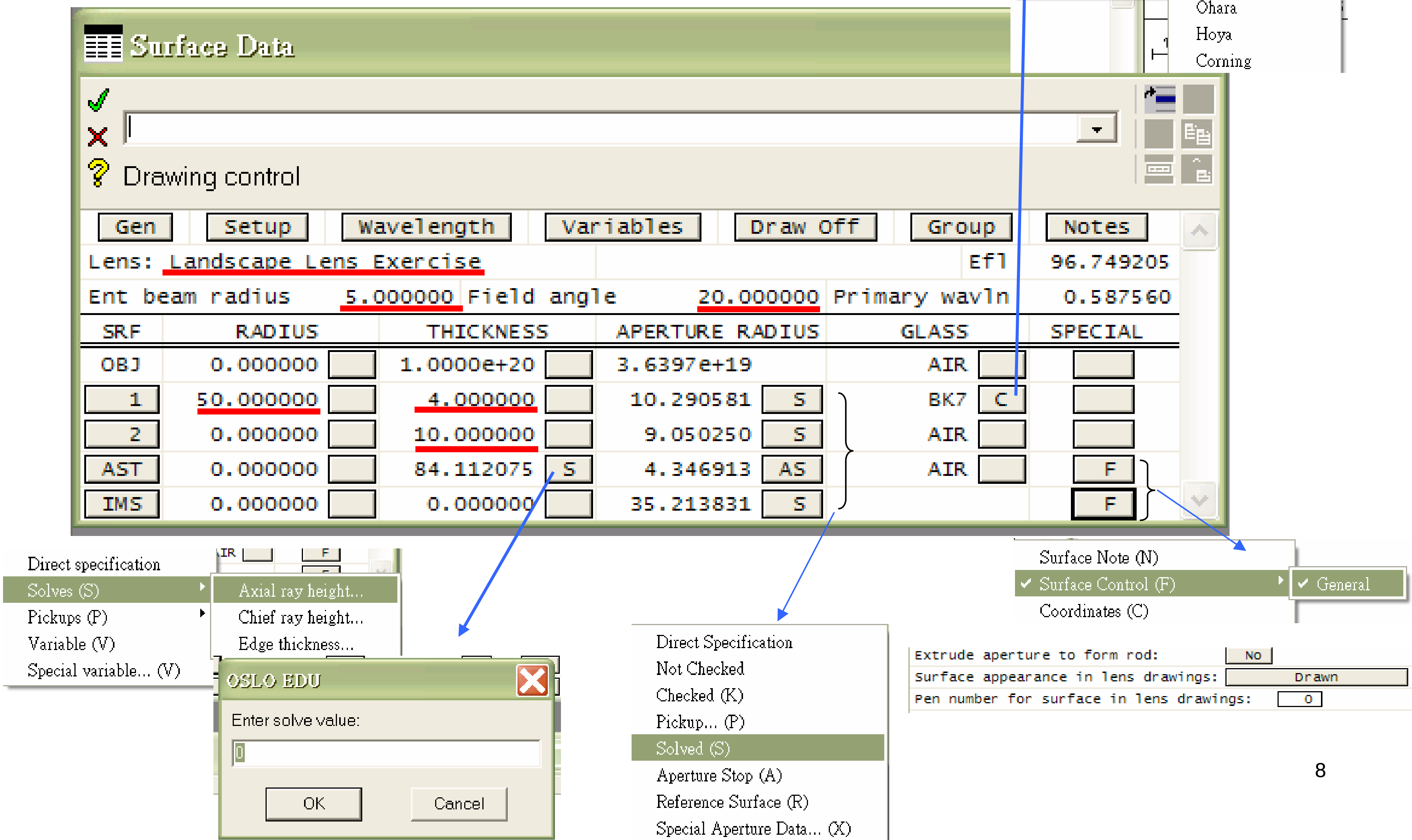

[Untitled lens] - OSLO EDU
File
Lens
Evaluate
Optimize
Tolerance
Source
Tools
Window
Help
New Lens... Ctrl+N
Open Lens... Ctrl+O
Save Lens Ctrl+S
Save Lens As...



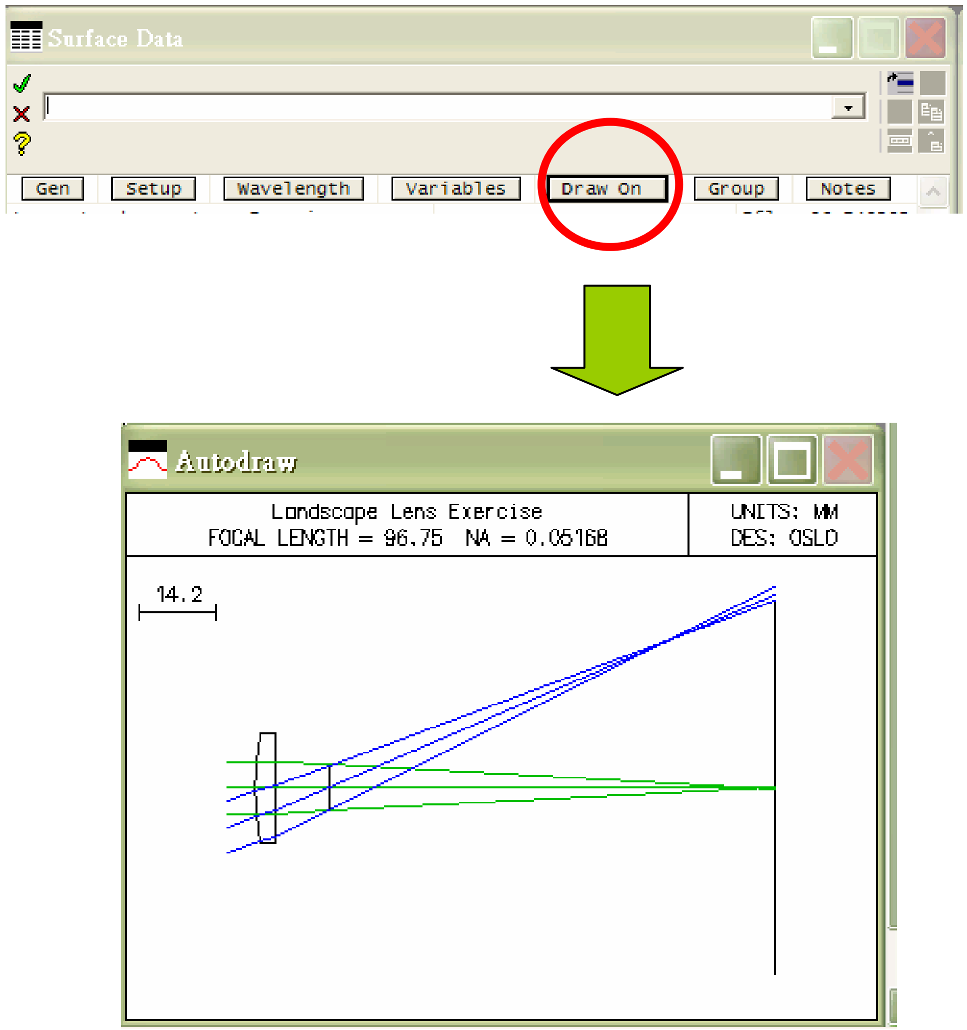

File new
New file name
Landscape 1
File type
Custom lens
Catalog lens
Perfect lens
Number of surfaces
3
1.000000
Focal length of perfect lens
0.000000
Magnification
0.050000
Image numerical aperture
OK
Cancel
Help

Lens entry, 3

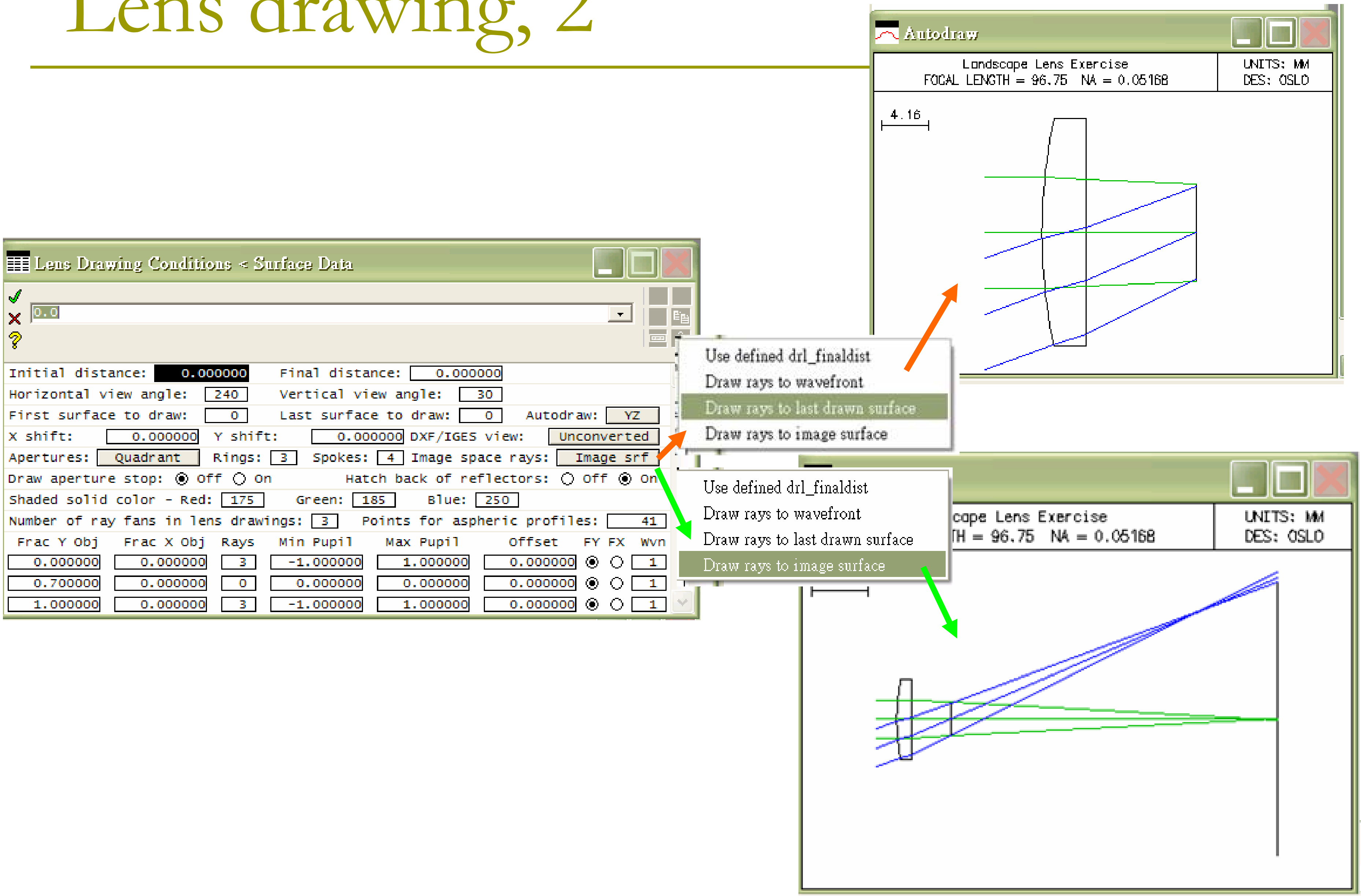

Air
Reflect
Reflect (hatch)
Pickup... (P)
Catalog (C)
Model... (M)
Direct...
Schott
Schott 2004
Schott RadHard
Ohara
Hoya
Corning


Surface Data
Drawing control
Gen
Setup
Wavelength
Variables
Draw Off
Group
Notes
Lens: Landscape Lens Exercise
Efl 96.749205
Ent beam radius 5.000000
Field angle 20.000000
Primary wavln 0.587560
SRF RADIUS THICKNESS APERTURE RADIUS GLASS SPECIAL
OBJ 0.000000 1.0000e+20 3.6397e+19 AIR
1 50.000000 4.000000 10.290581 S BK7 C
2 0.000000 10.000000 9.050250 S AIR
AST 0.000000 84.112075 S 4.346913 AS AIR F
IMS 0.000000 0.000000 35.213831 S F
Direct specification
Solves (S)
Pickups (P)
Variable (V)
Special variable... (V)
Axial ray height...
Chief ray height...
Edge thickness...
OSLO EDU
Enter solve value:
OK
Cancel
Direct Specification
Not Checked
Checked (K)
Pickup... (P)
Solved (S)
Aperture Stop (A)
Reference Surface (R)
Special Aperture Data... (X)
Surface Note (N)
Surface Control (F)
Coordinates (C)
General
Extrude aperture to form rod: No
Surface appearance in lens drawings: Drawn
Pen number for surface in lens drawings: 0

Lens drawing, 1

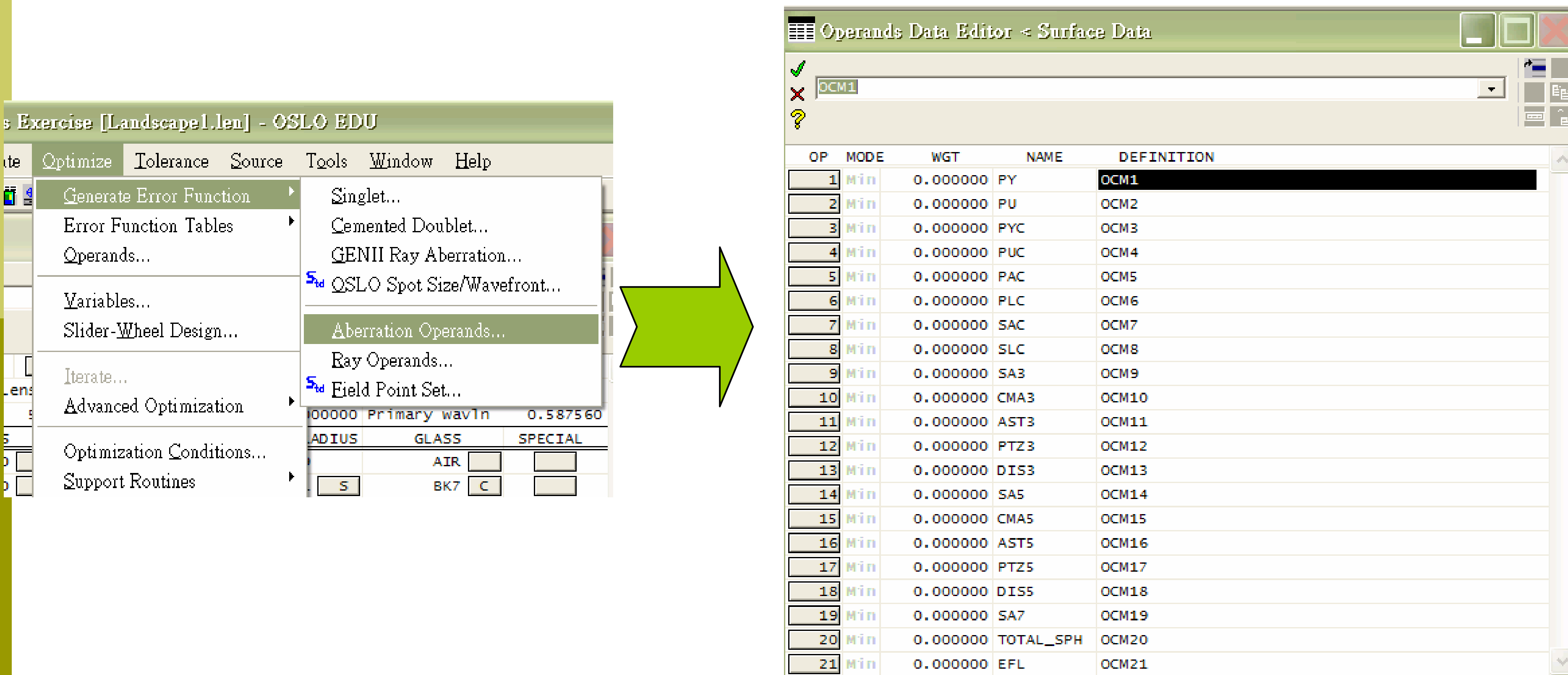


Lens drawing, 2



Optimization, 1

- We will define an error function that makes the focal length exactly 100 mm, and also eliminates the Seidel coma from the image.



Optimization, 2

OP	MODE	WGT	NAME	DEFINITION
1	Min	0.000000	PU	OCM2
2	Min	0.000000	CMA3	OCM10

PU operand is the axial ray slope leaving the lens.

Coma

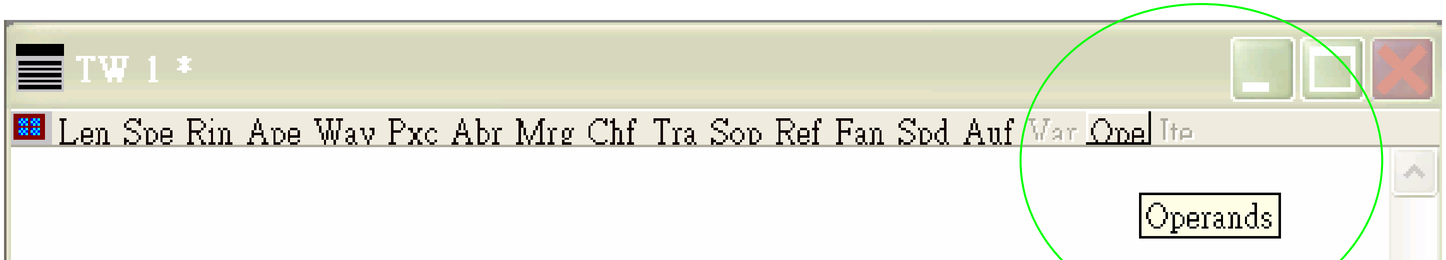
Beam radius = 5 mm
Effective focal length=100mm

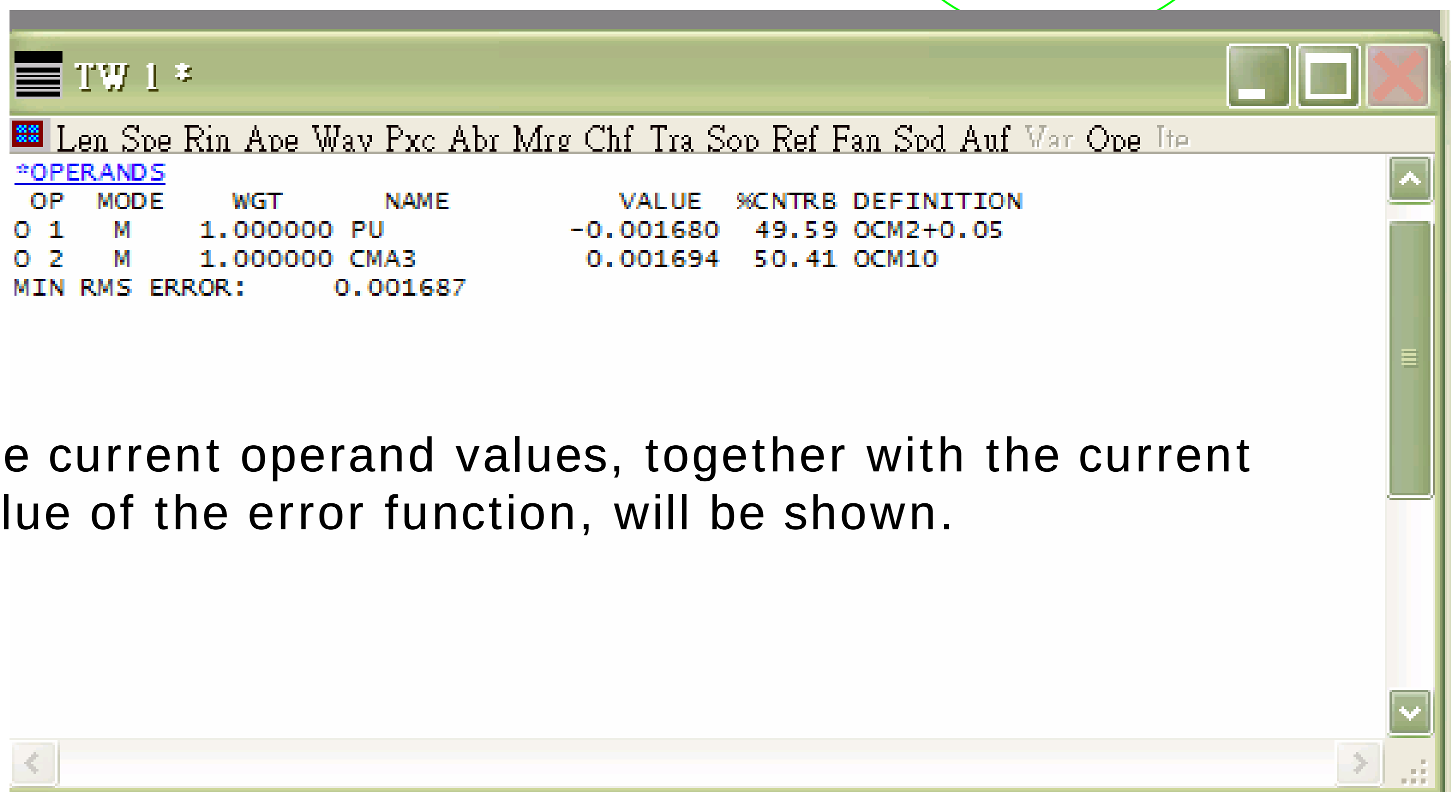
f-number = 10
PU=0.05 radian

In OSLO, all operands are targeted to zero.

OP	MODE	WGT	NAME	DEFINITION
1	Min	1.000000	PU	OCM2+0.05
2	Min	1.000000	CMA3	OCM10

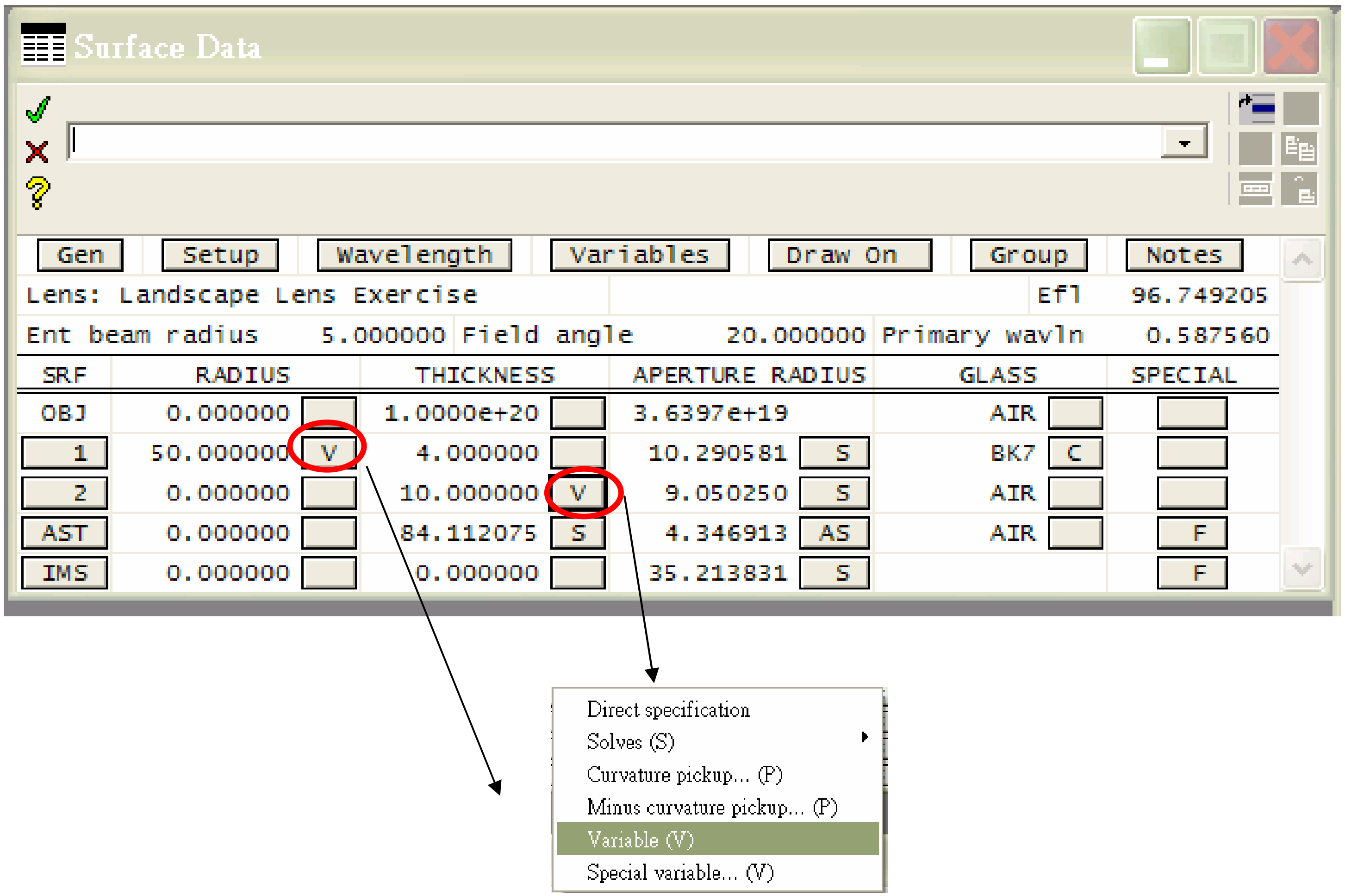
Optimization, 3





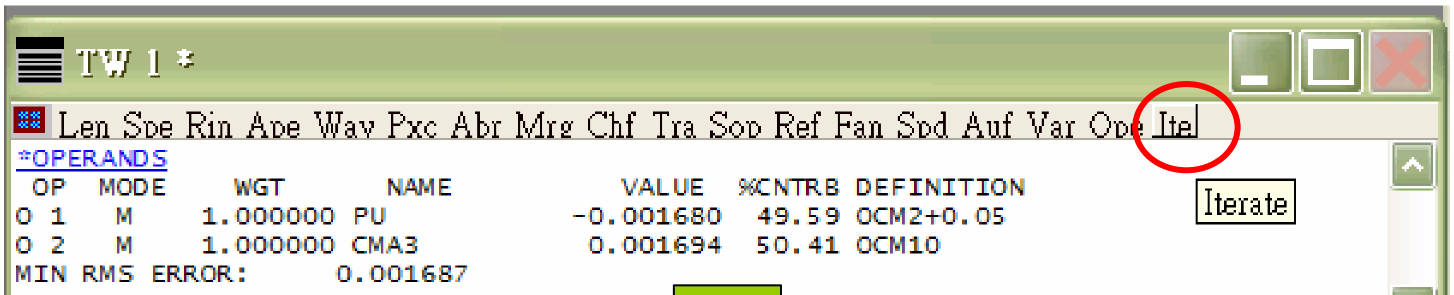
The current operand values, together with the current value of the error function, will be shown.

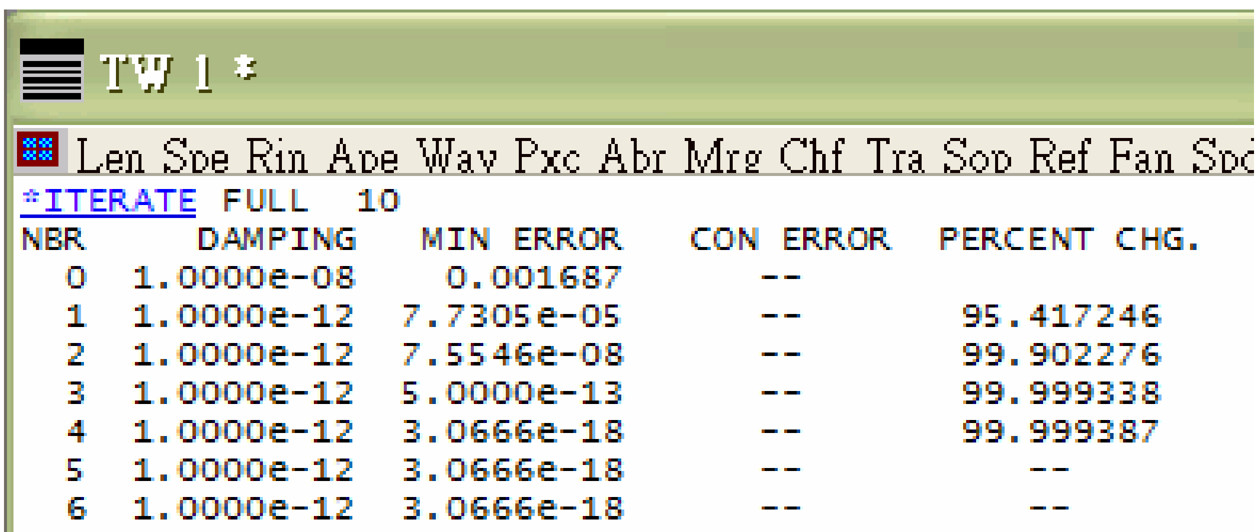
Optimization, 4



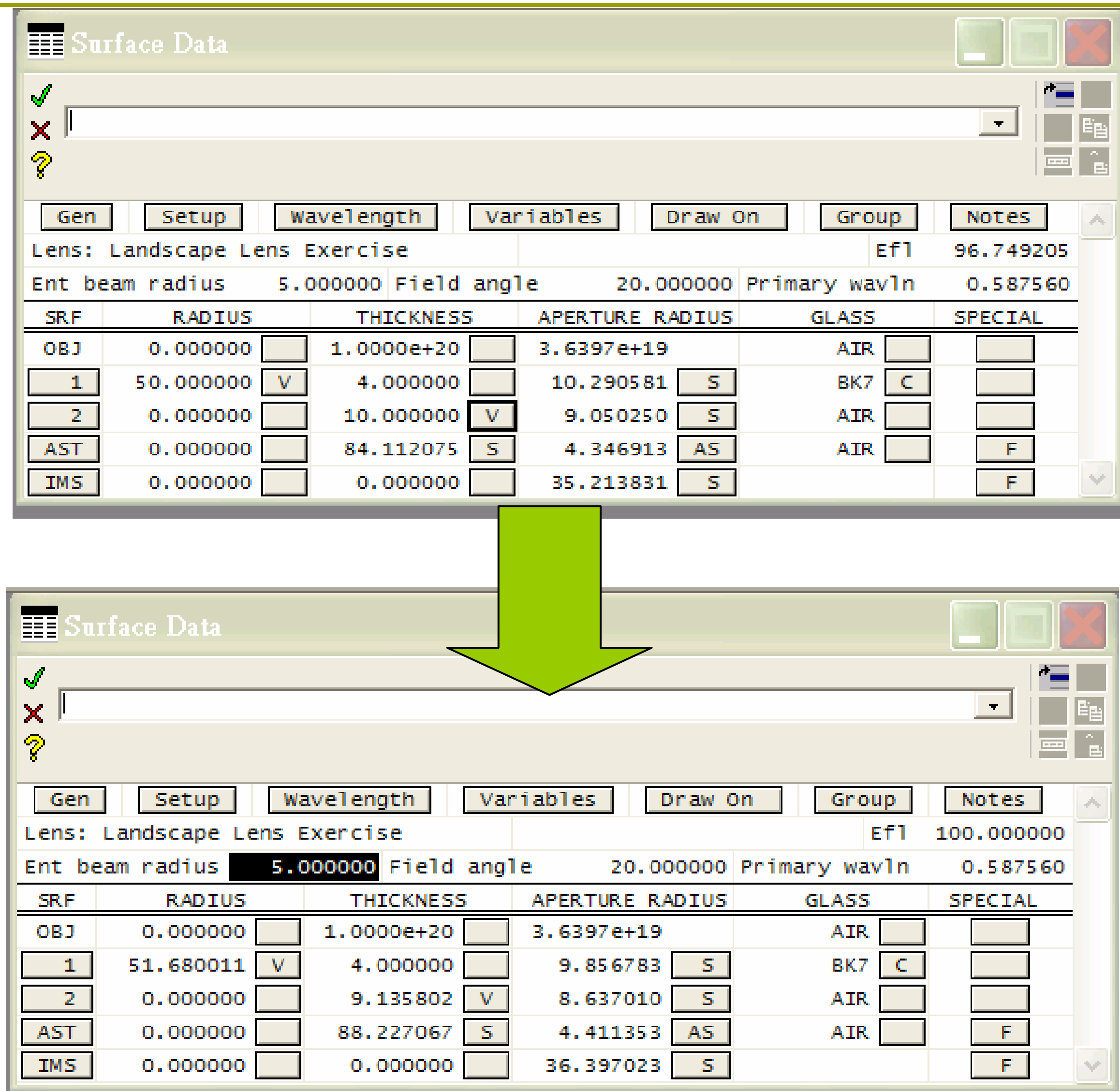
Optimization, 5

Before doing optimization, close the lens spreadsheet (Green check) and immediately re-open it.





Optimization, 6



Optimization, 7

TW 1 *

Len Spe Rin Ape Wav Pxc Abr Mrg Chf Tra Sop Ref Fan Spd Auf Var Ope Ite

Aberrations

*ITERATE FULL 10

NBR	DAMPING	MIN ERROR	CON ERROR	PERCENT CHG.
0	1.0000e-08	0.001687		
1	1.0000e-12	7.7305e-05	--	95.417246
2	1.0000e-12	7.5546e-08	--	99.902276

TW 1 *

Len Spe Rin Ape Wav Pxc Abr Mrg Chf Tra Sop Ref Fan Spd Auf Var Ope Ite

*PARAXIAL TRACE

SRF	PY	PU	PI	PYC	PUC	PIC
4	--	-0.050000	-0.050000	36.397023	0.412538	0.412538

*CHROMATIC ABERRATIONS

SRF	PAC	SAC	PLC	SLC
SUM	-0.077222	-0.053466	0.069914	0.048406

*SEIDEL ABERRATIONS

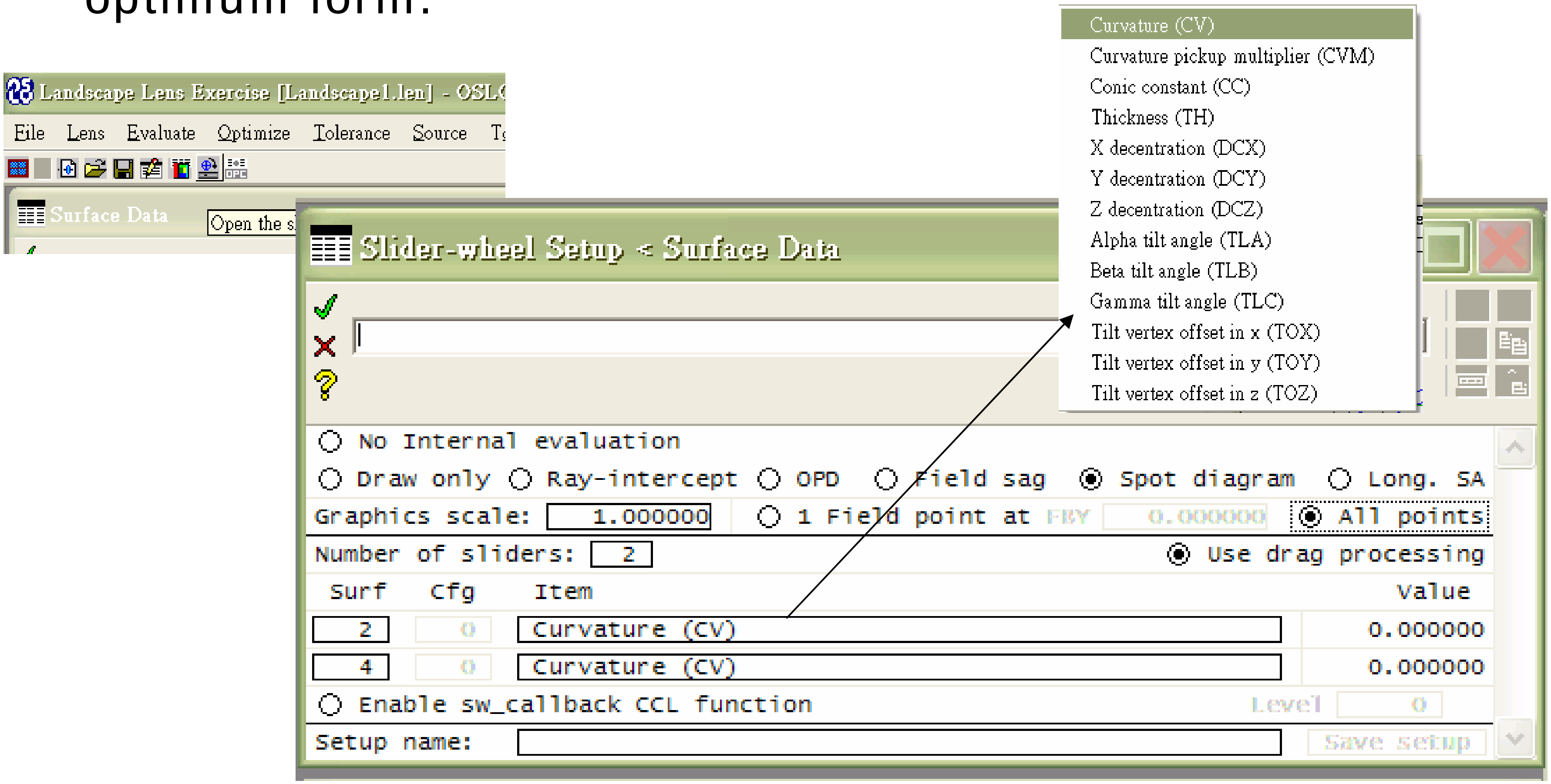
SRF	SA3	CMA3	AST3	PTZ3	DIS3
SUM	-0.013612	4.3368e-18	-0.313405	-0.218345	1.101908

*FIFTH-ORDER ABERRATIONS

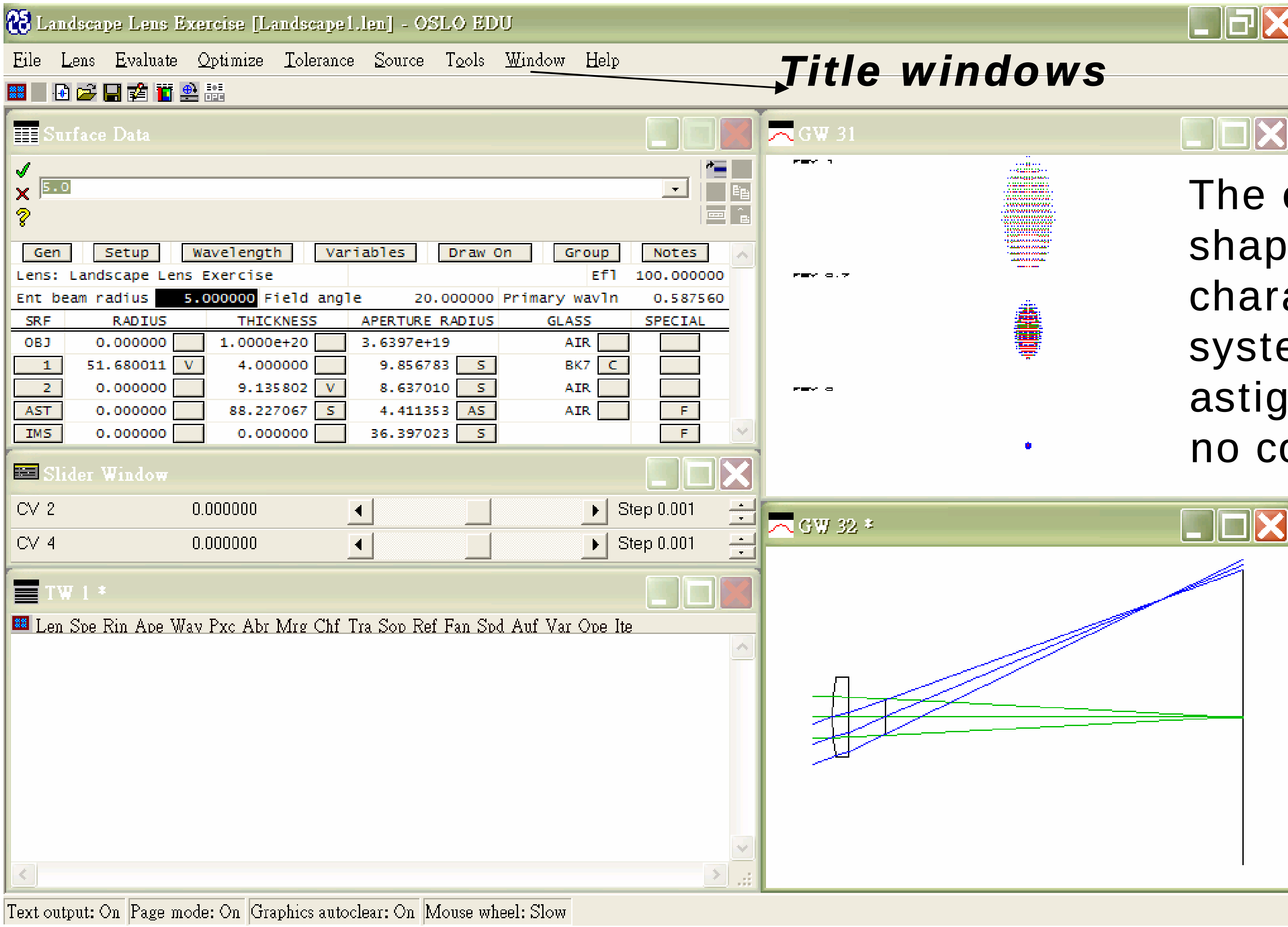
SRF	SA5	CMA5	AST5	PTZ5	DIS5	SA7
SUM	-9.6466e-05	-5.9253e-05	-0.020638	0.017274	0.070480	-7.7081e-07

Slider-wheel design, 1

- A landscape lens is normally a meniscus form. Next we show how to use OSLO's slider-wheel window to find the optimum form.

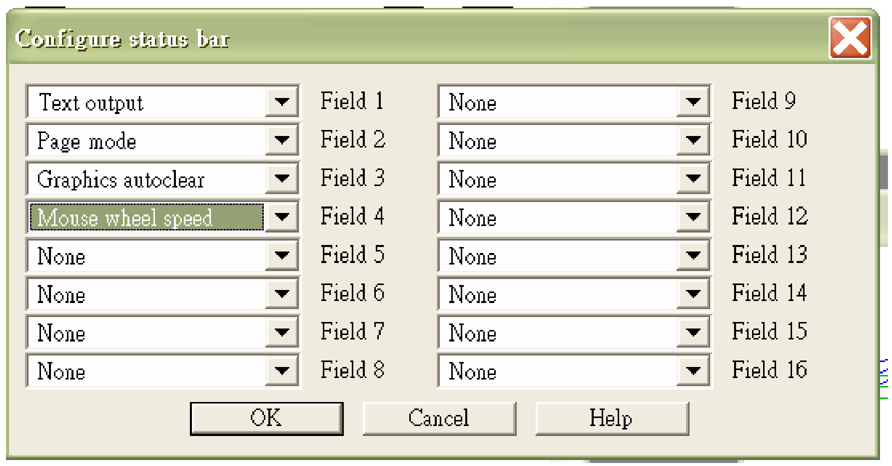


Slider-wheel design, 2

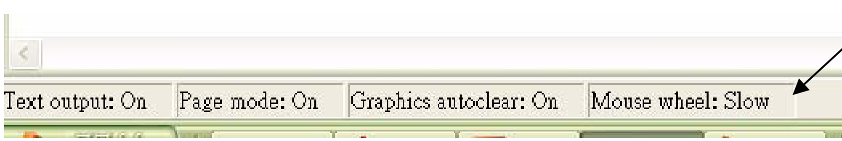


The elliptical shape is characteristic of a system with astigmatism, but no coma.

Slider-wheel design, 3



You change between fast and slow by clicking the mouse wheel itself.

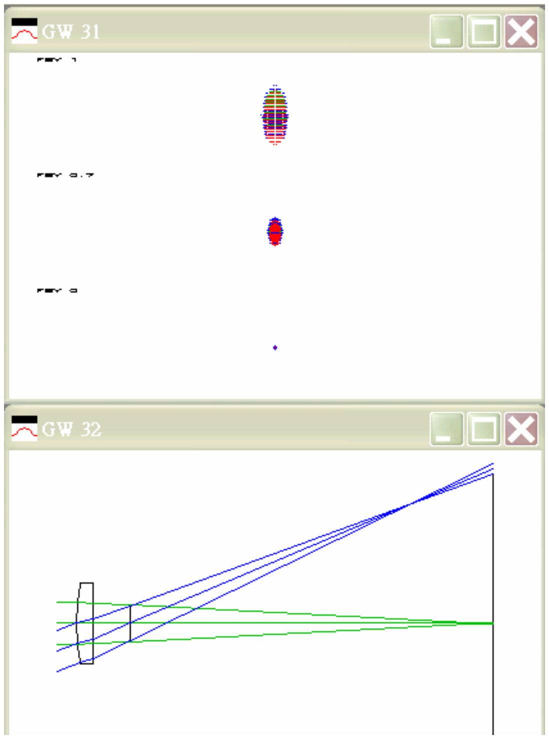


double click on the status bar in the main OSLO window.

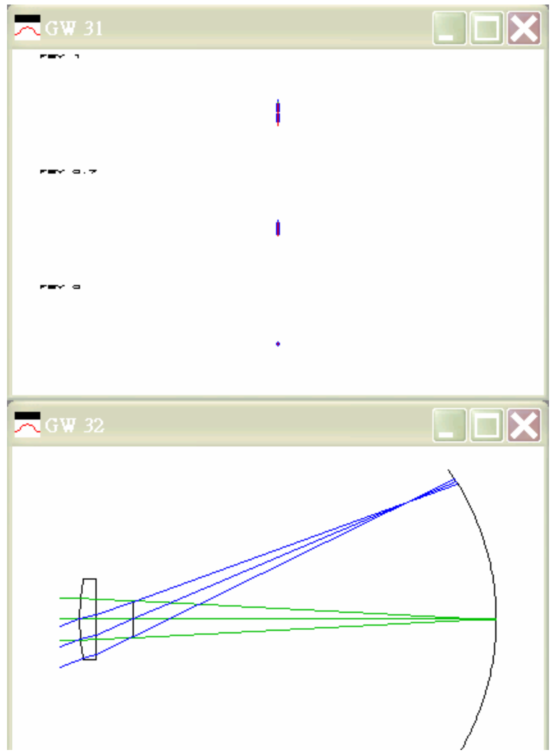
Slider-wheel design, 4

- If you make CV[2] negative, the lens becomes positive and the focal length gets smaller. The image quality changes, since the system is no longer free of coma. If you make CV[2] positive, the lens becomes first a meniscus with a long focal length, but eventually the lens becomes negative.
- When you change CV[4], you see that by making it negative, you can improve the size of the image off-axis, and in fact you can find a position where there is a line focus in the horizontal direction (tangential focus), or the vertical direction (sagittal focus). This is indicative of a system with no coma.

Slider-wheel design, 5

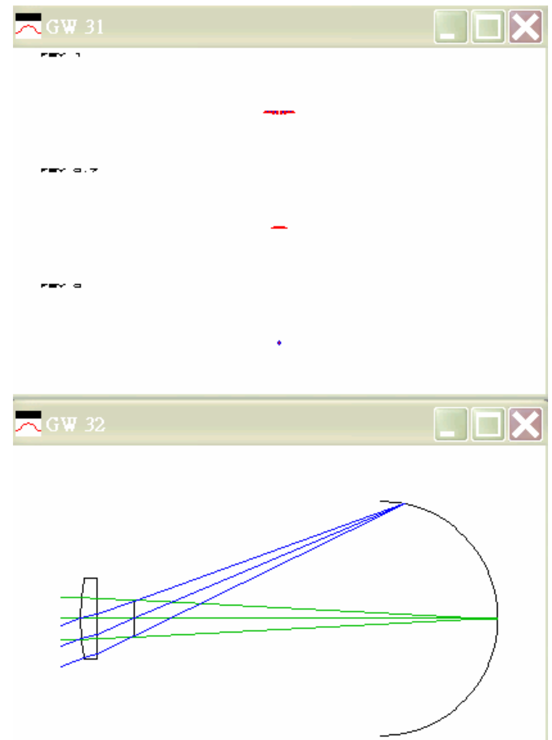


CV2=0, CV4=0



CV2=0, CV4=-0.016

sagittal focus

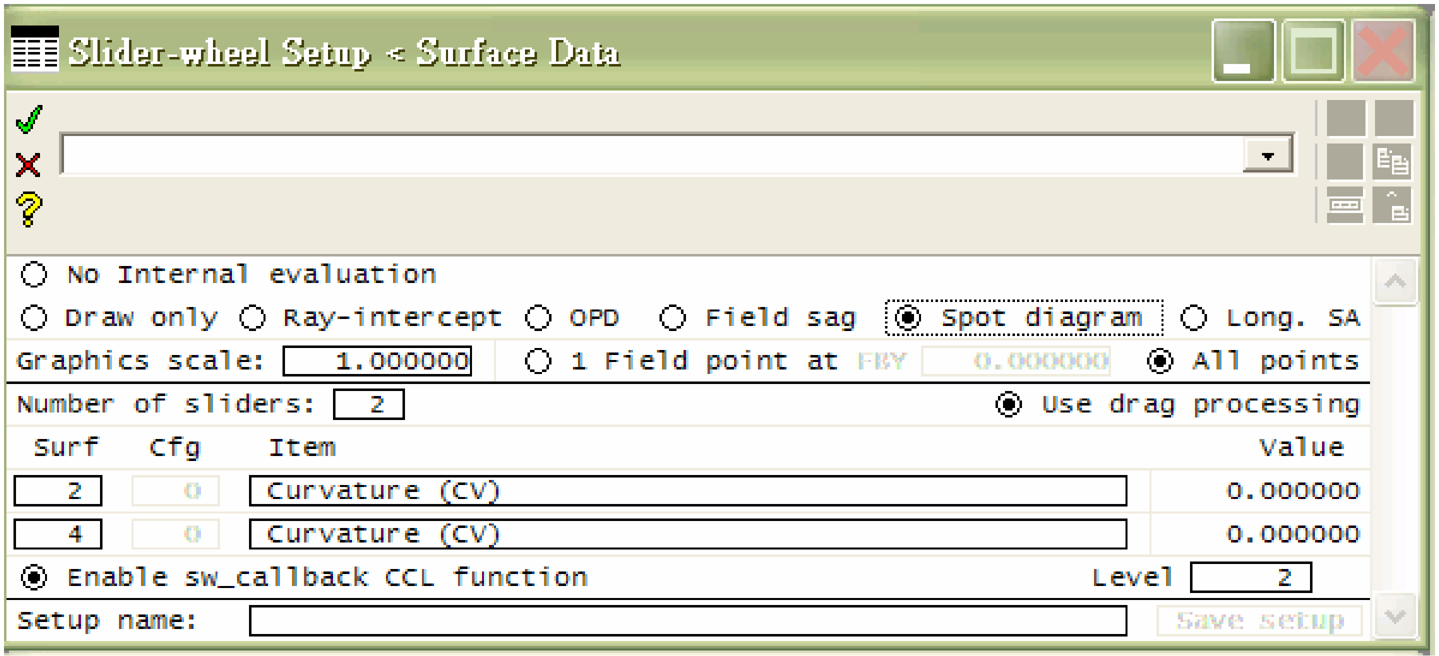


CV2=0, CV4=-0.035

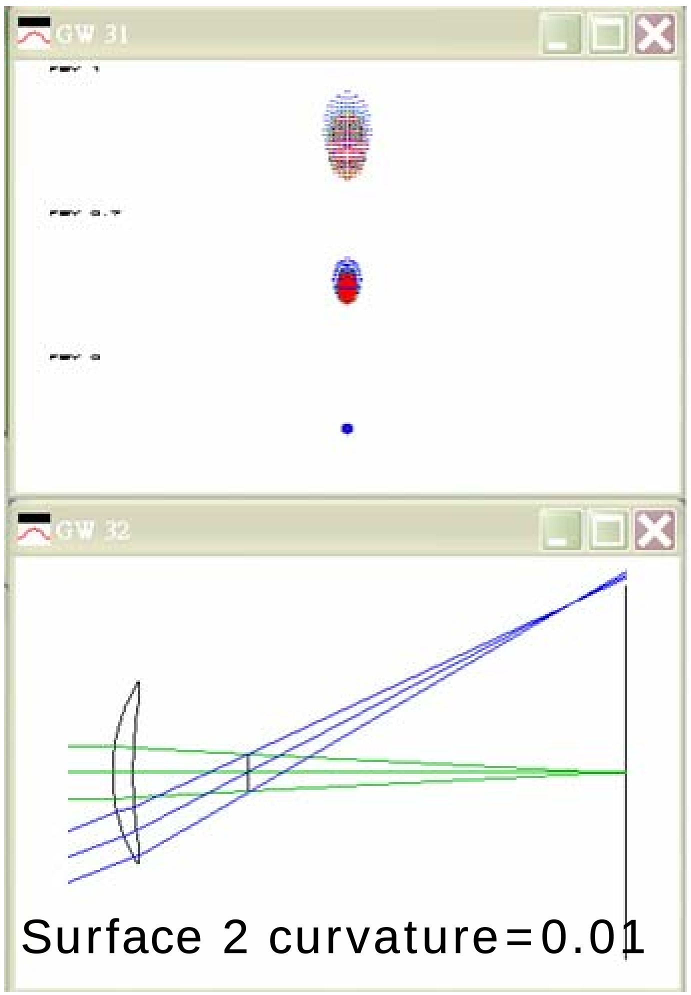
tangential focus

Slider-wheel design, 6

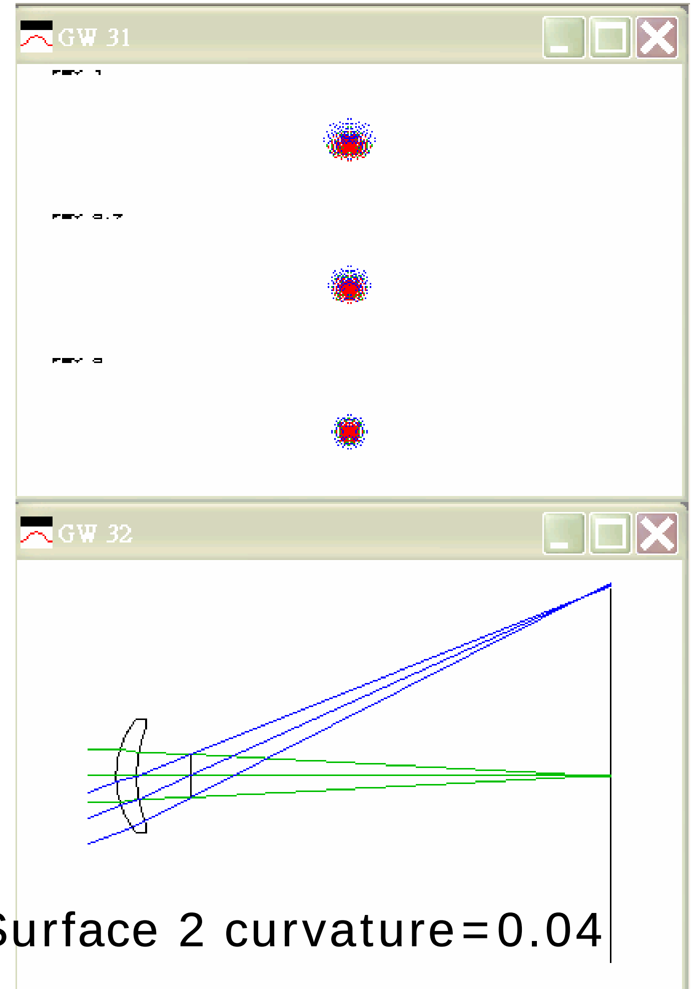
- The real power of sliders in OSLO comes when you allow the program to re-optimize the system as you drag a slider.



Slider-wheel design, 7



Surface 2 curvature=0.01



Surface 2 curvature=0.04

Slider-wheel design, 8

- The stop initially moves away from the lens as it becomes a meniscus, but as the bending becomes larger, the stop shift reverses and the aperture stop moves back towards the lens.

Optical materials

- The most important is often the ***dispersion***, but many other attributes must also be considered, such as ***thermal characteristics***, ***weight***, ***mechanical*** and ***chemical properties***, ***availability***, and ***cost***.

Dispersion, 1

- Sellmeier formula

$$n^2(\lambda) = 1.0 + \frac{b_1\lambda^2}{\lambda^2 - c_1} + \frac{b_2\lambda^2}{\lambda^2 - c_2} + \frac{b_3\lambda^2}{\lambda^2 - c_3}$$

- Laurent series, sometimes called the Schott formula

$$n^2(\lambda) = A_0 + A_1\lambda^2 + \frac{A_2}{\lambda^2} + \frac{A_3}{\lambda^4} + \frac{A_4}{\lambda^6} + \frac{A_5}{\lambda^8}$$

  - where λ is the wavelength in μm.

Dispersion, 2

- ***Conrady*** found that in the visible portion of the spectrum a good fit could be obtained using the formula

$$n(\lambda) = n_0 + \frac{A}{\lambda} + \frac{B}{\lambda^{3.5}}$$

- ***Buchdahl*** introduced a *chromatic coordinate* for accurately characterizing the refractive index.

$$\omega(\lambda) = \frac{\lambda - \lambda_0}{1 + 2.5(\lambda - \lambda_0)}$$

$$n(\omega) = n_0 + \nu_1\omega + \nu_2\omega^2 + \nu_3\omega^3 + \cdots$$

  - where the wavelength λ is expressed in μm and λ_0 is a reference wavelength, typically the d line (0.5876 μm) for visible light.

V number or Abbe number

- V (or ν) number, or Abbe number, is defined by

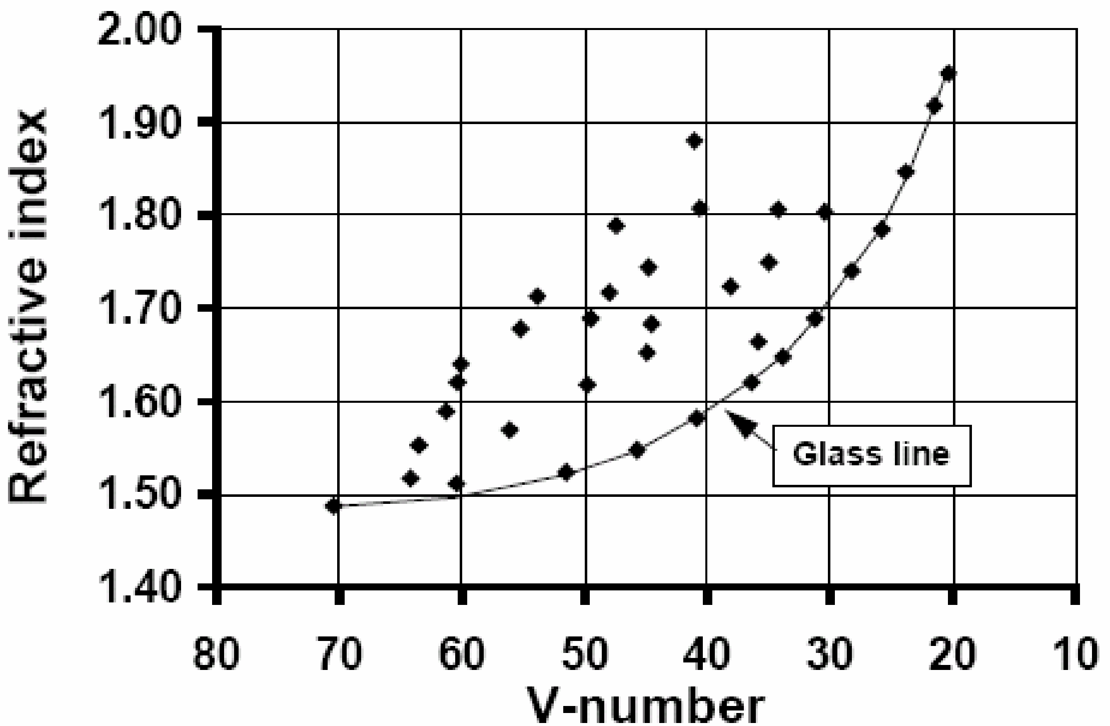
$$V \equiv \frac{n_d - 1}{n_F - n_C}$$

  - n_d: the refractive index at the helium d (0.5876 μm) line
  - n_F: the refractive index at the hydrogen F (0.4861 μm) line
  - n_C: the refractive index at the hydrogen C (0.6563 μm) line.

- In OSLO, wavelength 1 is taken to be the primary wavelength, wavelength 2 to be the short wavelength, and wavelength 3 to be the long wavelength.

Glass map, 1

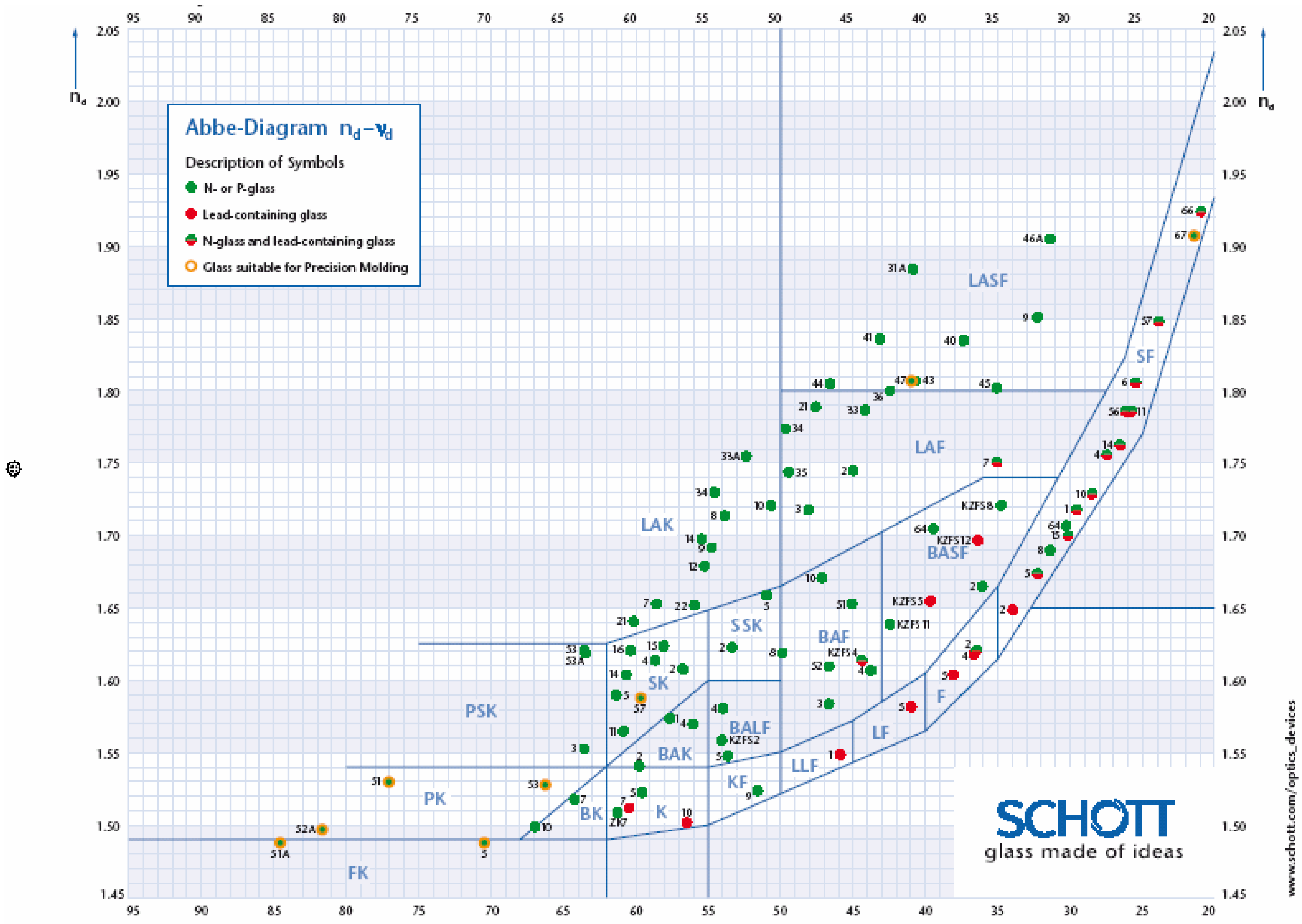
- The characteristics of optical glasses are often displayed on a two-dimensional graph, called a *glass map*.



Glass map, 2

- Most glasses lie along or near a line forming the lower right boundary of the region occupied by optical glasses. This line is called the ***glass line***.
- The availability of optical glasses that are located a considerable distance above the glass line gives the optical designer considerable flexibility **in correcting the chromatic (and other) aberrations** of optical systems.
- However, when an arbitrary choice is to be made, the glass chosen should be one on or near the glass line, since such glasses are **cheaper** and **more readily available**.

Glass map (Schott)



Material Properties Overview (Melles Griot), 1

Material	Usable Transmission Range	Index of Refraction	Features
BK7 N-BK7	BK7	1.52 @ 0.55 μm	Excellent all-around lens material provides broad transmission with excellent mechanical characteristics
LaSFN9	LaSFN9	1.86 @ 0.55 μm	High-refractive-index flint glass provides more power with less curvature
SF11	SF11	1.79 @ 0.55 μm	High-refractive-index flint glass provides more power with less curvature
F2	F2	1.62 @ 0.55 μm	Material represents a good compromise between higher index and acceptable mechanical characteristics
BaK1 N-BaK1	BaK1	1.57 @ 0.55 μm	Excellent all-around lens material, but has weaker chemical characteristics than BK7
Optical-Quality Synthetic Fused Silica (OQSFS)	OQSFS	1.46 @ 0.55 μm	Material provides good UV transmission and superior mechanical characteristics
UV-Grade Synthetic Fused Silica (UVGSFS)	UVGSFS	1.46 @ 0.55 μm	Material provides excellent UV transmission and superior mechanical characteristics
Optical Crown Glass	OPTICAL CROWN	1.52 @ 0.55 μm	This lower tolerance glass can be used as a mirror substrate or in non-critical applications

0.1 0.5 1.0 5.0 10.0

WAVELENGTHS IN μm

Material Properties Overview (Melles Griot), 1

Material	Usable Transmission Range	Index of Refraction	Features
Low-expansion borosilicate glass (LEBG)	LEBG	1.48 @ 0.55 µm	Excellent thermal stability, low cost, and homogeneity makes LEBG useful for high-temperature windows, mirror substrates, and condenser lenses
Sapphire	SAPPHIRE	1.77 @ 0.55 µm	Excellent mechanical and thermal characteristics make it a superior window material
Zinc Selenide	ZINC SELENIDE	2.40 @ 10.6 µm	Zinc selenide is most popular for transmissive IR optics; transmits visible and IR, and has low absorption in the red end of the spectrum
Calcium Fluoride	CALCIUM FLUORIDE	1.399 @ 5 µm	This popular UV excimer laser material is used for windows, lenses, and mirror substrates
ZERODUR®	ZERODUR®	1.55 @ 0.55 µm	Highly homogeneous glass-ceramic with near-zero coefficient of thermal expansion is ideal for mirror substrates for stringent applications
Calcite	CALCITE	1.66@ 0.55 µm	Naturally occuring negative uniaxial crystal with pronounced birefringence makes this material suitable for polarizing prisms
α-BBO	α-BBO	1.66@ 0.55 µm	Pronounced birefringence, transmission to 189 nm and high-damage threshold properties of this material are ideal for polarizing prisms
	0.1 0.5 1.0 5.0 10.0 WAVELENGTHS IN µm		

Lens Design and Optimization Procedure

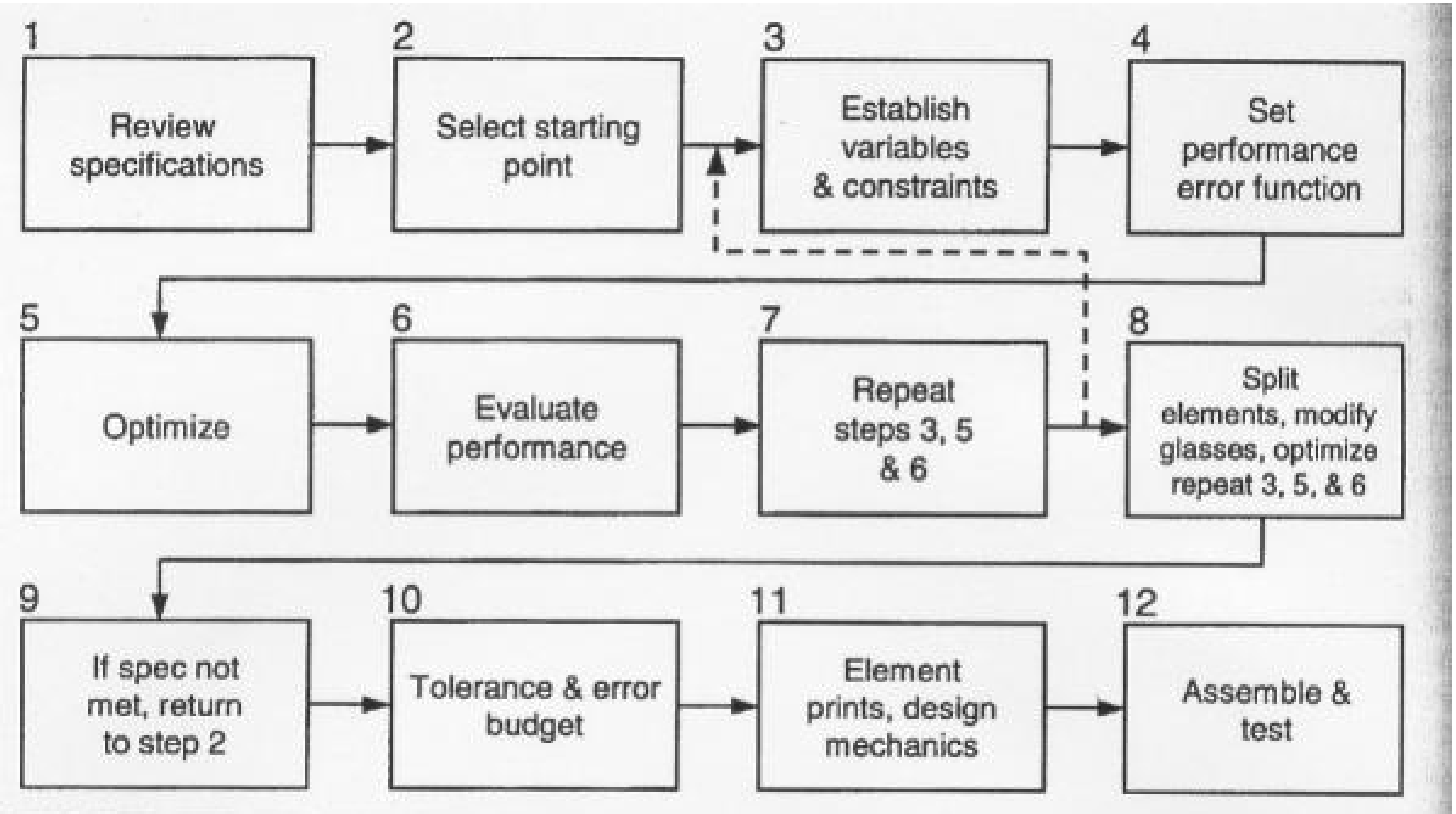


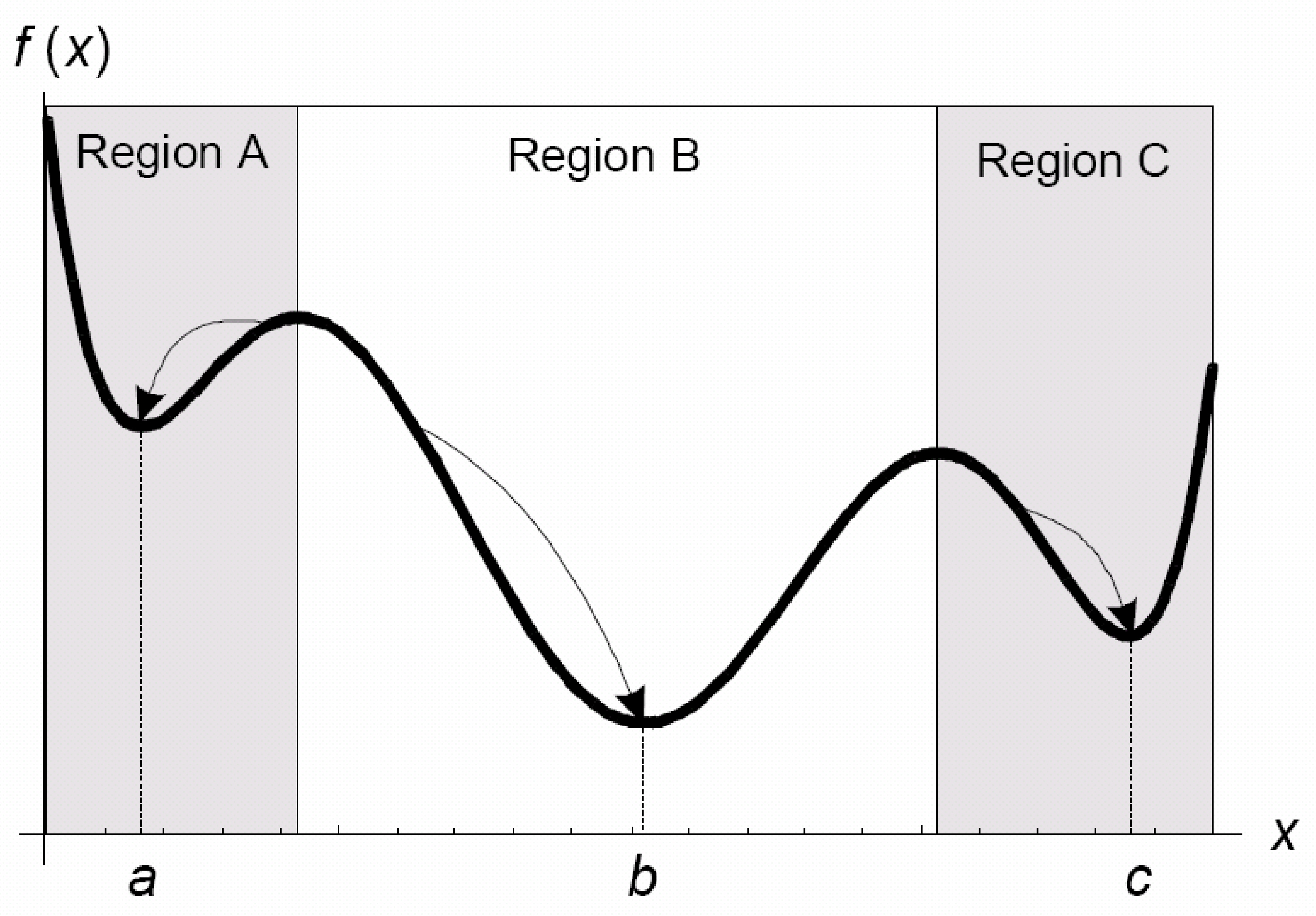
Figure 9.2 Lens Design and Optimization Procedure

Fisher, Optical system design

Optimization, 1

- ***optimization*** in optical design refers to the improvement of the performance of an optical system by changing the values of a subset of the system's constructional parameters (*variables*).
- The variables are quantities such as surface curvatures, element and air-space thicknesses, tilt angles, etc.
- The system's performance is measured by ***a user-defined error function***, which is the weighted sum of squares of *operands*, that represents an estimate of the difference in performance between a given optical system and a system that meets all the design requirements.

Optimization, 2



Approach to optimization

- the user chooses initial values for the variables and an optimization algorithm is applied that repeatedly attempts to find new values for the variables that yield ever lower error function values.
- ***This approach depends heavily upon the choice of the starting point.***
- ***Starting points are typically determined by experience or by finding an existing design with properties similar to those desired.***
- Most of optimization methods employed in optical design are *least-squares methods*,

Default tolerances in OSLO

Property	Maximum dimension of part (mm)			
	Up to 10	Over 10 Up to 30	Over 30 Up to 100	Over 100 Up to 300
Edge length, diameter (mm)	± 0.2	± 0.5	± 1.0	± 1.5
Thickness (mm)	± 0.1	± 0.2	± 0.4	± 0.8
Angle deviation of prisms and plate	± 30′	± 30′	± 30′	± 30′
Width of protective chamfer (mm)	0.1 – 0.3	0.2 – 0.5	0.3 – 0.8	0.5 – 1.6
Stress birefringence (nm/cm)	0/20	0/20	–	–
Bubbles and inclusions	1/3x0.16	1/5x0.25	1/5x0.4	1/5x0.63
Inhomogeneity and striae	2/1;1	2/1;1	–	–
Surface form tolerances	3/5(1)	3/10(2)	3/10(2) 30 mm diameter	3/10(2) 60 mm diameter
Centering tolerances	4/30′	4/20′	4/10′	4/10′
Surface imperfection tolerances	5/3x0.16	5/5x0.25	5/5x0.4	5/5x0.63

These tolerance values are taken from the ISO 10110 standard.

Typical optical fabrication tolerances

	Surface Quality	Diameter, mm	Deviation (concentricity) min	Thickness, mm	Radius	Regularity (asphericity)	Linear Dimension, mm	Angles
Low cost	120-80	± 0.2	> 10	± 0.5	Gage	Gage	± 0.5	Degrees
Commercial	80-50	± 0.07	3–10	± 0.25	10 Fr	3 Fr	± 0.25	± 15′
Precision	60-40	± 0.02	1–3	± 0.1	5 Fr	1 Fr	± 0.1	± 5′–10′
Extraprecise	60-40	± 0.01	< 1	± 0.05	1 Fr	⅕ Fr	As req'd.	Seconds
Plastic	80-50		1	± 0.02	10 Fr	5 Fr	0.02	minutes

Ref: W. Smith, Optical modern engineering