Introduction to Optical Modeling

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Lecture 3

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Course Overview

Part 1: Geometrical optics based modeling and design (U.D. Zeitner)

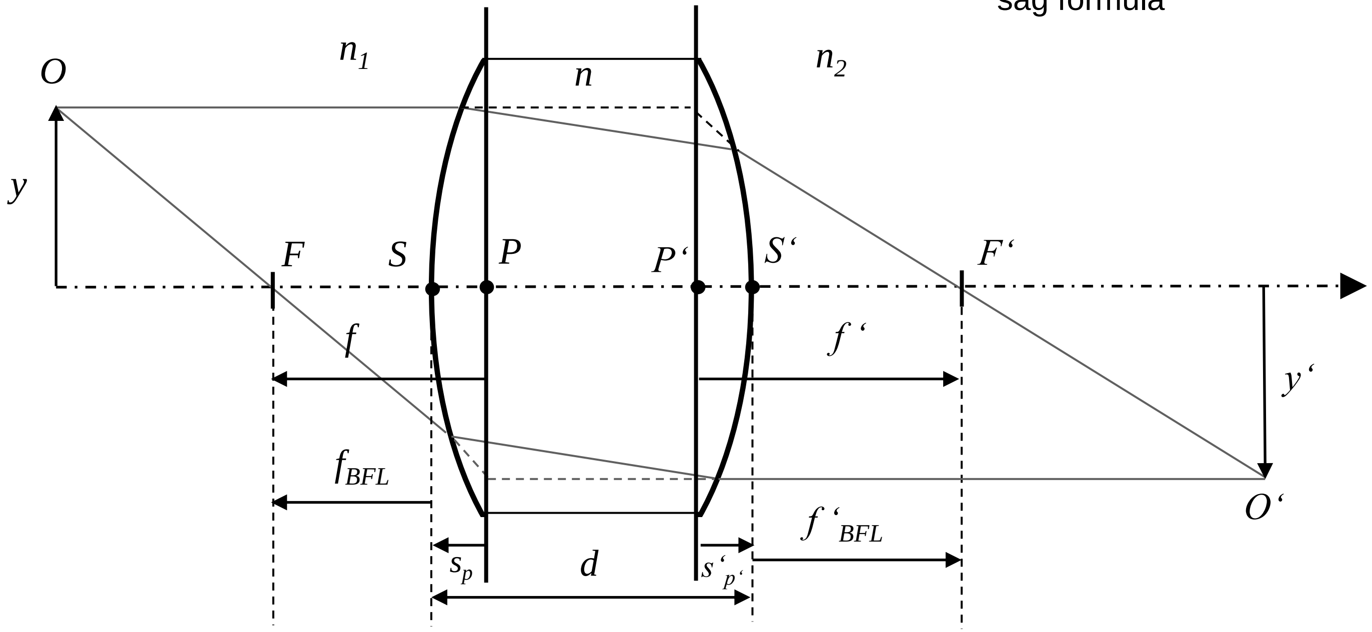
1. Introduction
2. Paraxial approximation / Gaussian optics
3. ABCD-matrix formalism
4. **Real lenses**
5. **Optical materials**
   - glass types, dispersion
   - chromatic aberrations
6. Imaging systems
   - apertures/stops, entrance-/exit-pupil
   - wavefront aberrations

Part 2: Wave-optics based modeling (F. Wyrowski)

2.4 Real Lens

→ refraction at two surfaces according to Eq. (2.1), spaced at a distance d

sag formula



f'_{BFL} ... back focal length (measured from vertex point S')
P, P' ... principle planes → planes of 'apparent' ray deflection
S, S' ... vertex points of the surfaces (intersection of the optical axis)

Definition: $\Phi = -\frac{n_1}{f} = \frac{n_2}{f'}$ refractive power (2.20)

Thin Lens

"thin lens": → radii of curvature large compared to the lens thickness

i.e. $|c_{1/2} \cdot d| \ll 1$

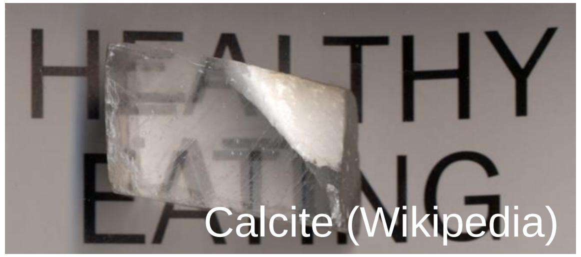
→ principle planes coincide and $f' = f'_{BFL}$

If $n_1 = n_2 = 1$ (lens in air):
$$\frac{1}{f'} = (n-1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) \tag{2.21}$$

more general: if d is not negligible
$$\Phi = \frac{1}{f'} = (n-1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) + \frac{(n-1)^2 \cdot d}{n \cdot R_1 \cdot R_2} \tag{2.22}$$

2.5 Optical Materials


Schott



Calcite (Wikipedia)


light-microscope.net

Typical optical materials:
- Glasses
- Crystals
- Plastics
- Liquids
- Gases
- Glues and Cements

Important in the optical design: complex refractive index

$$\tilde{n}(\lambda) = \sqrt{\tilde{\varepsilon}_r(\lambda)} = n(\lambda) + i \cdot \kappa(\lambda)$$

absorption: $$\alpha = \frac{4\pi}{\lambda}\kappa = 2k_0\kappa$$

Data-sheets of optical glasses: values given relative to air at <u>normal conditions</u>
$T = 293\mathrm{K}$ $\quad p = 1013\mathrm{mbar}$

Here: restrict ourselves to (isotropic) dielectric materials → transparent materials

Fit Equations for Material Dispersion

λ[µm]

Cauchy: $$n(\lambda) = A_0 + \frac{A_1}{\lambda^2} + \frac{A_2}{\lambda^4}$$

Sellmeier: $$n(\lambda) = \sqrt{\frac{k_1\lambda}{\lambda^2 - L_1} + \frac{k_2\lambda}{\lambda^2 - L_2} + \frac{k_3\lambda}{\lambda^2 - L_3} + 1}$$

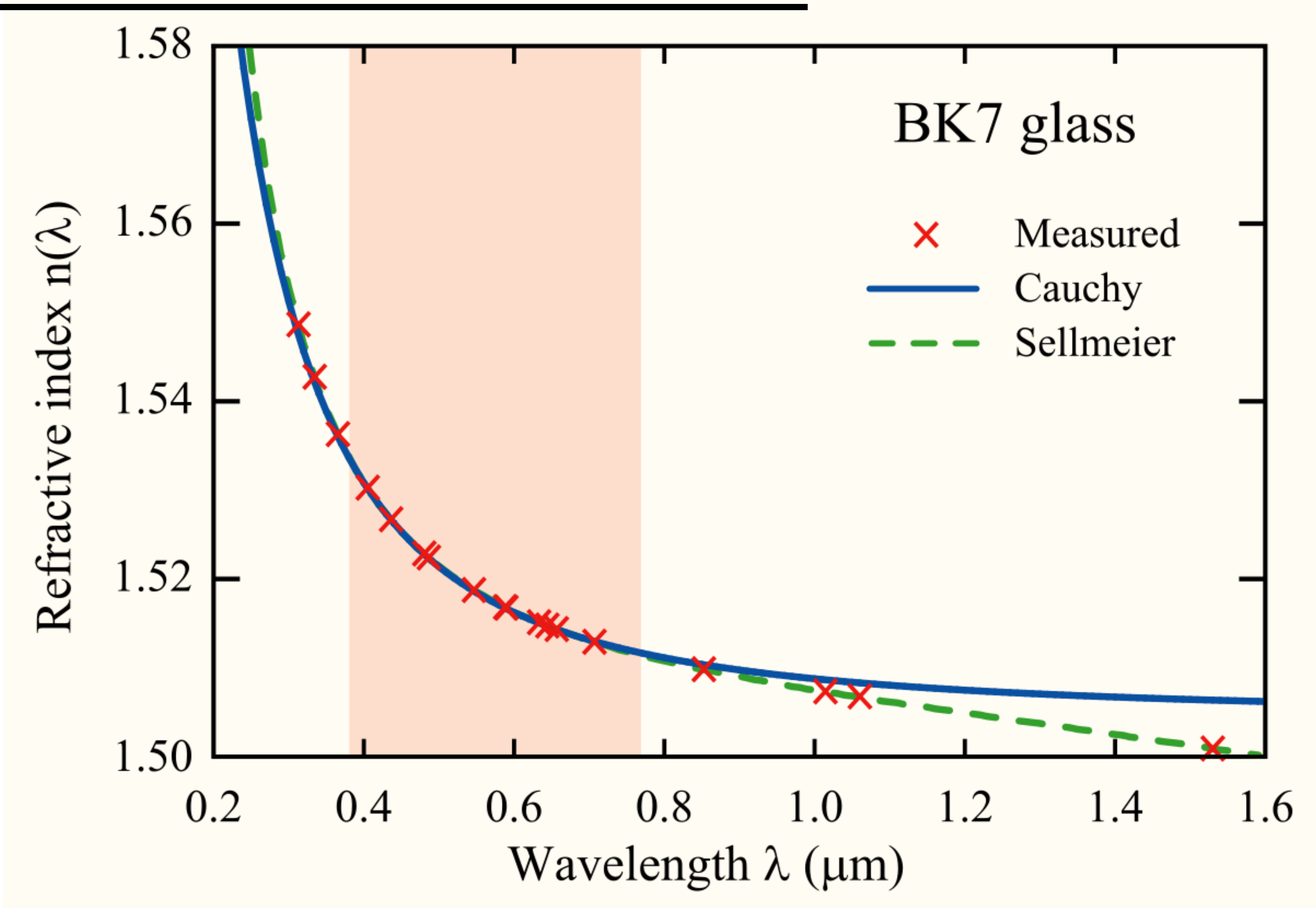
Schott-formula: $$n(\lambda) = \sqrt{A_0 + A_1\lambda^2 + \frac{A_2}{\lambda^2} + \frac{A_3}{\lambda^4} + \frac{A_4}{\lambda^6} + \frac{A_5}{\lambda^8}}$$

Herzberger (IR-region): $$n(\lambda) = A + BL + CL^2 + D\lambda^2 + E\lambda^4 + F\lambda^6$$

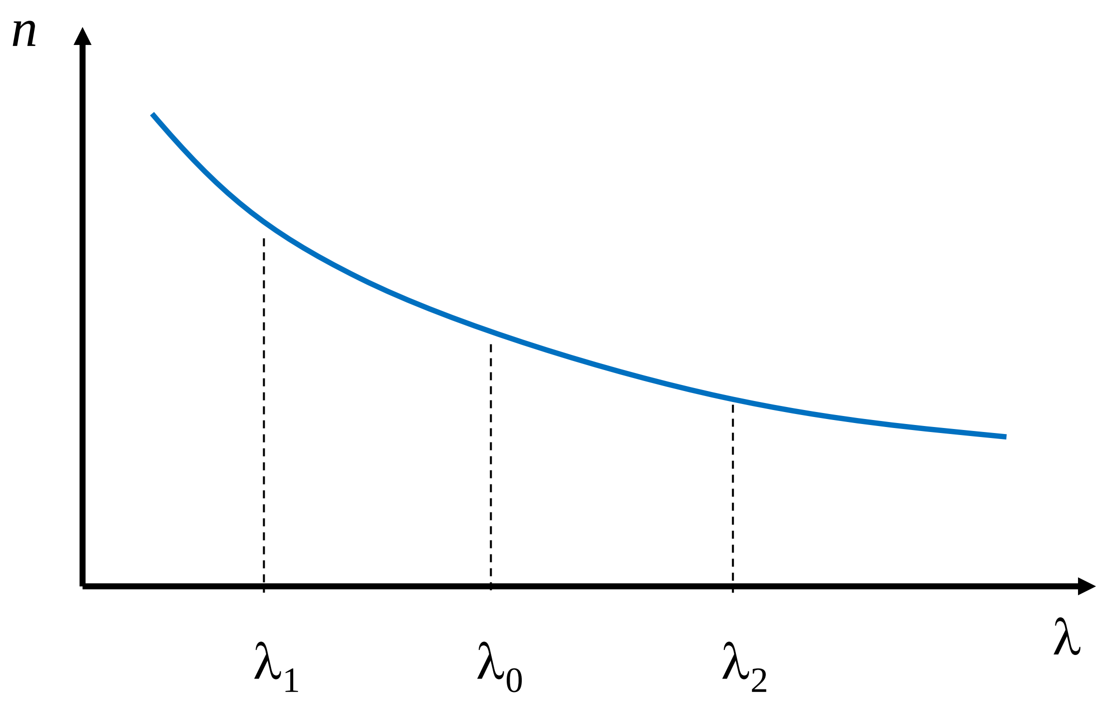
with $L = {}^{1}/_{(\lambda^2 - 0.028)}$

Drude (metals): $$n^2(\lambda) - k^2(\lambda) = A_0 - \frac{A_1 A_2^2 \lambda^2}{\lambda^2 + A_2^2} \qquad 2n(\lambda)k(\lambda) = \frac{A_1 A_2 \lambda^3}{\lambda^2 + A_2^2}$$

Dispersion of BK7 glass



Dispersion in the optical design



λ_0 … primary wavelength
λ_1, λ_2 … secondary wavelengths / colors

Specific choice (typical):

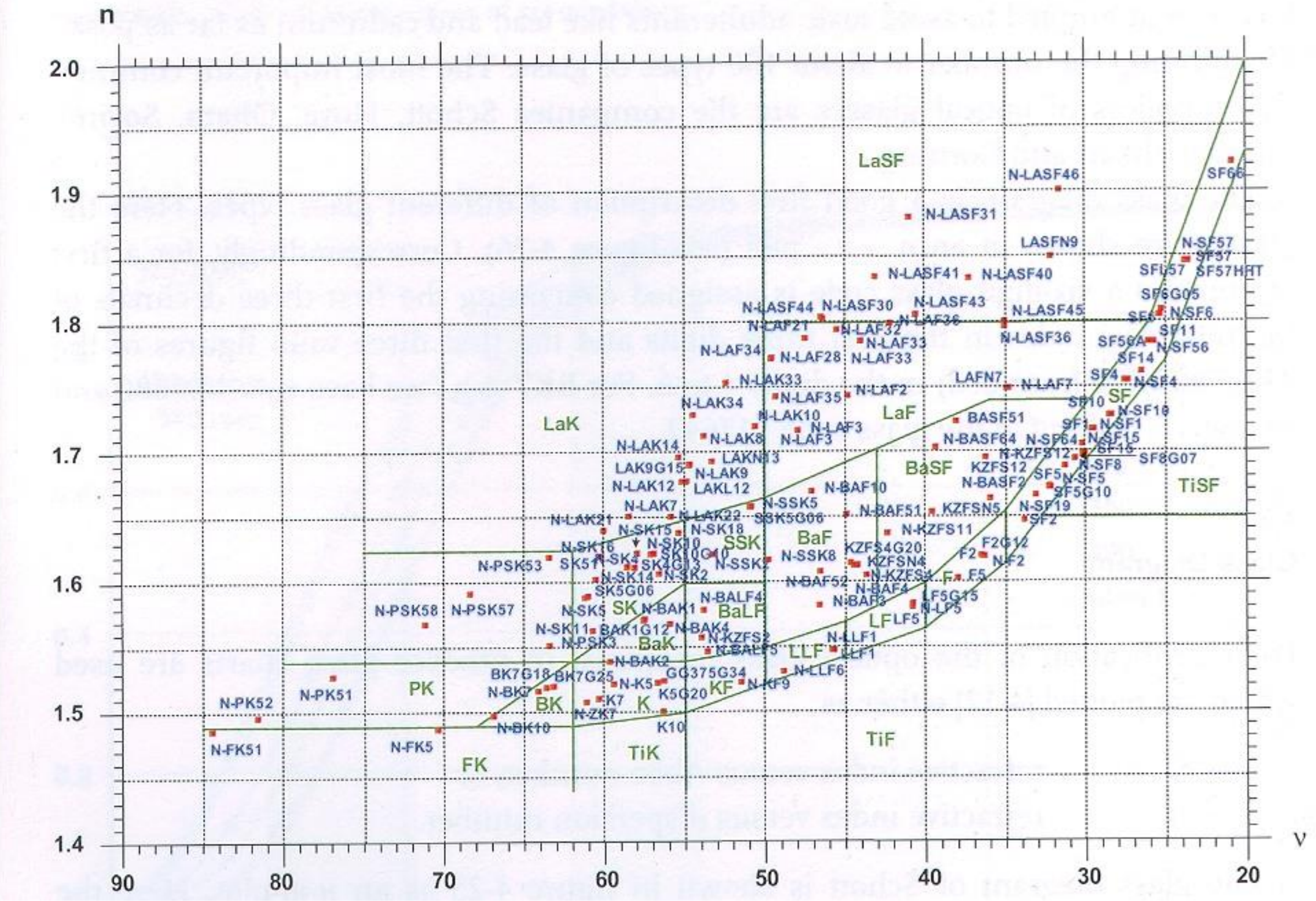
I) $\lambda_e = 546.07$ nm, $\lambda_{F'} = 480.0$ nm, $\lambda_{C'} = 643.8$ nm — microscopy

II) $\lambda_d = 587.56$ nm, $\lambda_F = 486.1$ nm, $\lambda_C = 656.3$ nm — photography

Wavelengths of the most important spectral lines.

λ in [nm]	Name	Color	Element
248.3		UV	Hg
280.4		UV	Hg
296.7278		UV	Hg
312.5663		UV	Hg
334.1478		UV	Hg
365.0146	i	UV	Hg
404.6561	h	violet	Hg
435.8343	g	blue	Hg
479.9914	F′	blue	Cd
486.1327	F	blue	H
546.0740	e	green	Hg
587.5618	d	yellow	He
589.2938	D	yellow	Na
632.8		red	HeNe laser
643.8469	C′	red	Cd
656.2725	C	red	H
706.5188	r	red	He
852.11	s	NIR	Cs
1013.98	t	NIR	Hg
1060.0		IR	Nd-glass laser
1529.582		IR	Hg line in the IR
1970.09		IR	Hg line in the IR
2325.42		IR	Hg line in the IR

Glass Diagram



Glass Diagram

Definition:

crown glass: $n < 1.6$ $\nu_e > 55$
$n > 1.6$ $\nu_e > 50$

flint glass: $n < 1.6$ $\nu_e < 55$
$n > 1.6$ $\nu_e < 50$

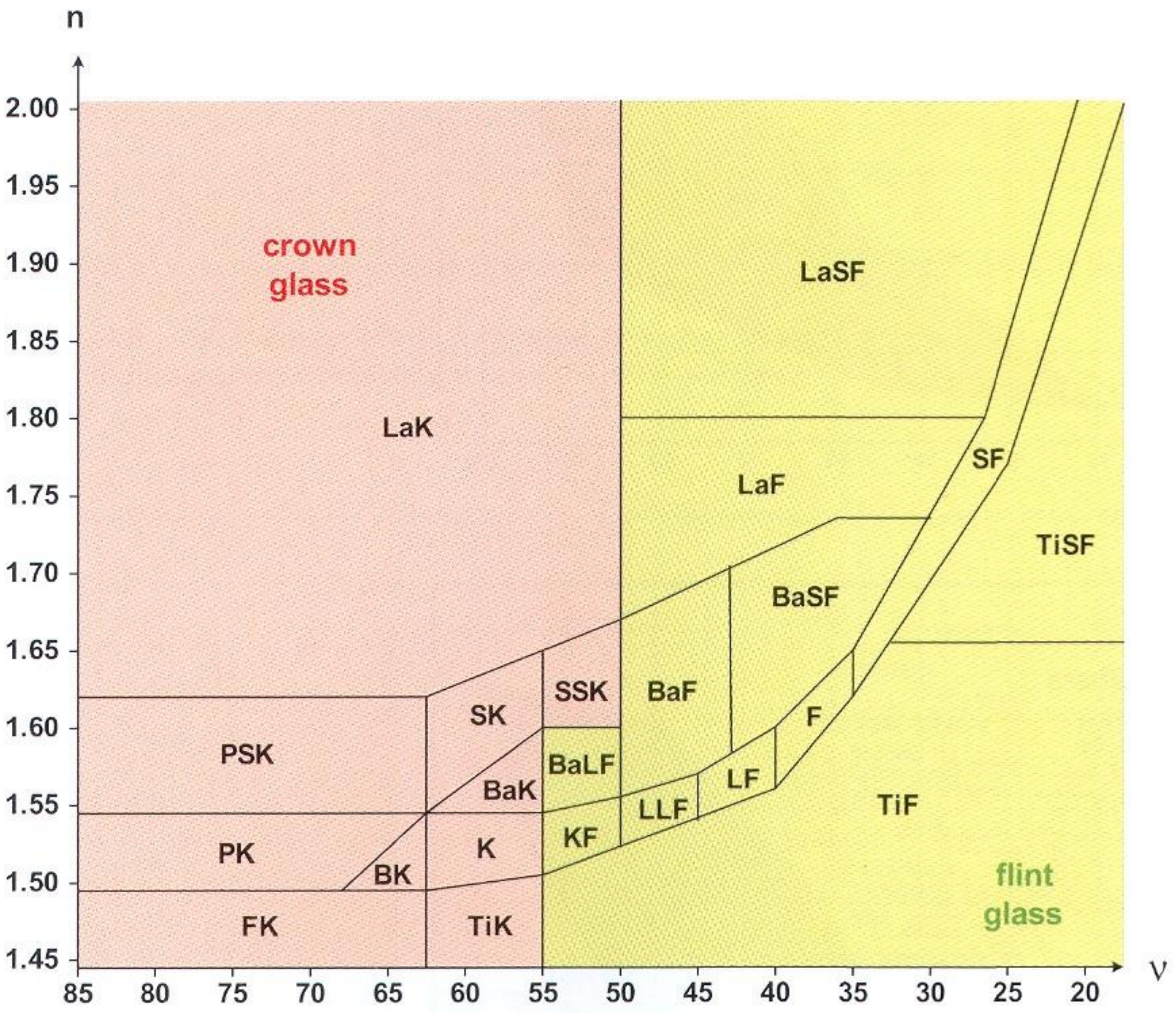
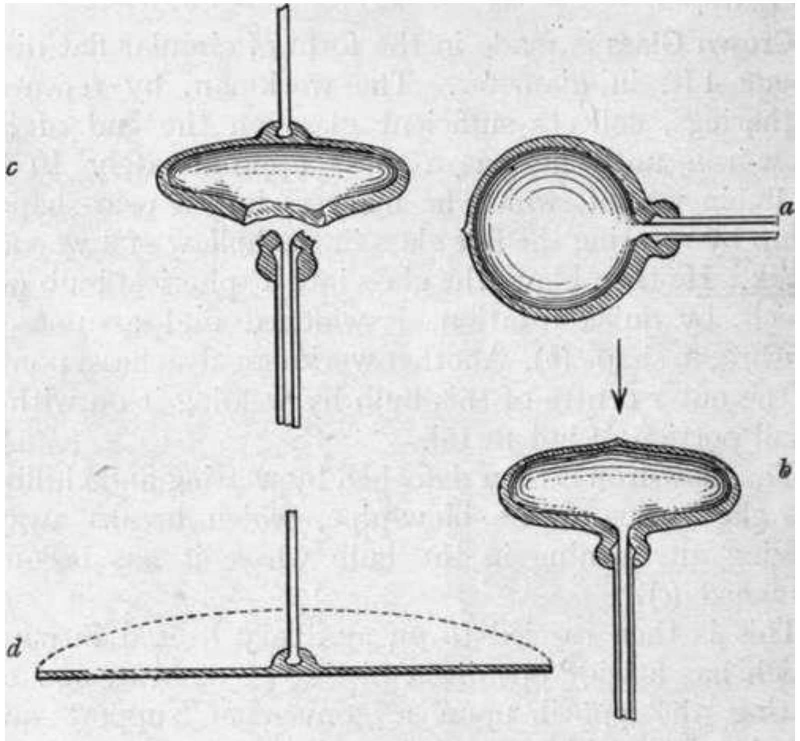
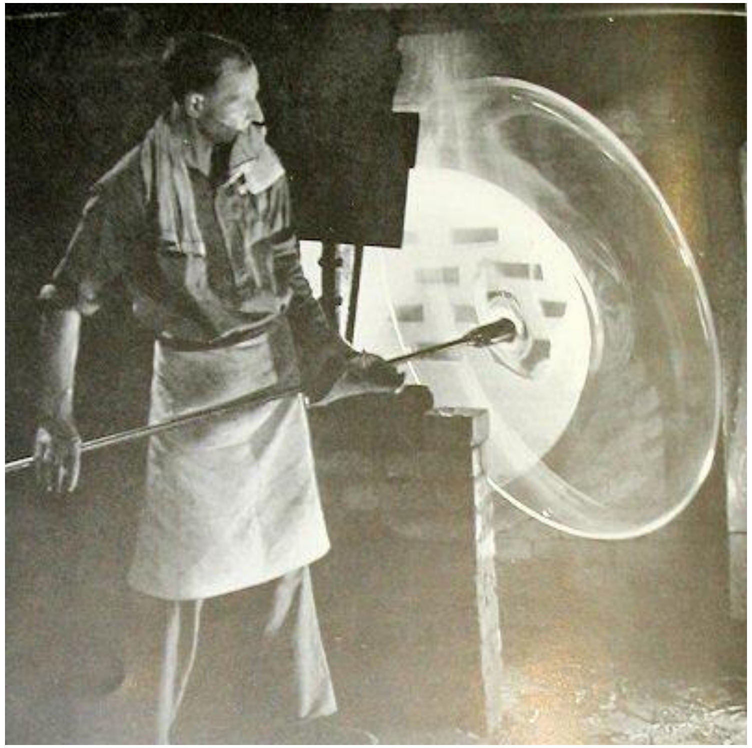


Figure 4-28: Glass diagram of Schott. Division into ranges of glass families.

Crown Glass (historic)





historic window

Flint Glass (historic)

term stems from **flint nodules** (found in chalk deposits)
→ flint-stone

source of high purity silica,
used to produce lead containing glasses (starting in 17th century)
(traditionally 4-60% lead oxide content)

today typically replaced by TiO_2 and ZrO_2

wikipedia.org