FN-Optiklabor-Prismen-EN-v0.1-2026-05-17

Research Note — Prisms

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1. Thesis

Module 05 (Lenses) showed chromatic aberration as a **disturbing** effect: because the refractive index $n(\lambda)$ is wavelength-dependent, lenses fan out colours and create colour fringes. Module 07 (Light Sources) showed that different sources have different spectra. Module 06 (Prisms) connects both and reverses the perspective: **the same dispersion effect that disturbs in lenses becomes a usable tool in the prism — the prism spatially decomposes light into its spectrum and thereby makes the spectrum of every light source visible.** The naive assumption "refraction is colour-independent" is refuted threefold: through the measurable dispersion, through the visibly different source spectra and through the angle-dependent minimum deviation. This note is the historical foundation of spectroscopy (Newton, Fraunhofer, Kirchhoff/Bunsen).

2. Assumptions

1. Ray optics (geometrical optics), diffraction negligible for macroscopic prism.
2. Snell's law of refraction at both prism faces.
3. Sellmeier dispersion equation for the refractive index $n(\lambda)$ of real glass (BK7 crown, SF11 flint).
4. Homogeneous, isotropic glass (no birefringence).
5. Idealised source spectra from Module 07 (Planck, fluorescent lines, sodium).
6. Deviation angle and minimum deviation from standard prism geometry.

3. Mathematical model

M1 — "refraction is colour-independent": One refractive index n for all wavelengths; the prism deflects all colours by the same angle.

M2 — dispersion: The refractive index depends on wavelength (Sellmeier):

$$n^2(\lambda) = 1 + \sum_{i} \frac{B_i\,\lambda^2}{\lambda^2 - C_i}.$$

Shorter wavelengths (violet) have higher n → stronger refraction → splitting.

M3 — source spectrum visible: Each wavelength is deflected by its own angle; the spatial pattern is the spectrum of the source. Continuous spectrum (incandescent) → rainbow band; line spectrum (fluorescent, sodium) → discrete lines.

M4 — deviation angle and minimum deviation: For incidence angle θ_i, prism angle A and index n:

$$\delta = \theta_i + \arcsin\!\big(n\sin(A - \arcsin(\tfrac{\sin\theta_i}{n}))\big) - A.$$

The deviation angle has a **minimum** at symmetric passage:

$$\delta_{\min} = 2\arcsin\!\big(n\sin\tfrac{A}{2}\big) - A.$$

At too shallow incidence, **total internal reflection** occurs at the second face.

Symbol	Meaning	Unit
$n(\lambda)$	refractive index	—
A	prism angle (apex)	°
θ_i	incidence angle	°
δ	deviation angle	°
$\delta_{\min}$	minimum deviation	°
B_i, C_i	Sellmeier coefficients	—

4. Parameters

Three scenarios:

Scenario	Setup
A dispersion	60° prism, incidence 50°, BK7 + SF11, red (656 nm) vs. violet (405 nm)
B source spectra	60° prism, incidence 50°, BK7, incandescent / fluorescent / sodium
C minimum deviation	60° prism, BK7 at 589 nm, incidence 30°–80°

Tolerance set in advance: $\varepsilon = 0.1°$ angular resolution. Rationale: 0.1° is well visible (corresponds to ~2 mm offset at 1 m projection distance).

5. Prediction

Scenario	Expectation
A	Violet refracted more than red, angular difference $> \varepsilon$; flint stronger than crown
B	Incandescent → broad band, fluorescent → lines, sodium → one line
C	Deviation angle has a minimum at symmetric passage; total

6. Falsification criterion

M1 (“refraction is colour-independent”) is refuted if **any** holds: - The angular difference between red and violet exceeds ε (dispersion). - Different sources produce visibly different spatial patterns (coverage difference > 0.3). - The deviation angle varies with incidence angle and has a minimum (instead of being constant).

7. Competing models

- **K1 — colour-independent refraction (M1):** tested baseline model.
- **K2 — dispersion / Sellmeier (M2):** wavelength-dependent index.
- **K3 — diffraction grating:** also decomposes light spectrally, but through interference (Module 01), not refraction — complementary principle, higher resolution.
- **K4 — grating spectrometer / spectroscope:** instrumental application.
- **K5 — rainbow in nature:** dispersion + total reflection in water droplets — own sub-topic.
- **K6 — achromatic doublet:** crown + flint combined to cancel dispersion (Module 05, reverse application).
- **K7 — prism spectrometer with calibration:** quantitative wavelength measurement via known lines.

8. Domain of failure

- **Very small prisms / narrow beams:** diffraction becomes relevant (Module 03), resolution limited.
- **Very strongly dispersive glass at shallow incidence:** total reflection prevents passage (observed in the model for SF11 at 50°, hence steeper incidence chosen).
- **Absorbing glasses:** some wavelengths swallowed in the glass — distorts the spectrum.
- **Birefringence:** in anisotropic crystals (calcite) two rays — own topic.
- **Nonlinear optics:** at extremely high intensity (laser) frequency doubling etc. — irrelevant here.
- **Polarisation:** the Brewster-angle effect at the faces is ignored.

9. Simulation

Numerical evaluation in `prismen_simulation.py`:

1. Sellmeier equation for BK7 and SF11, $n(\lambda)$ over 380–780 nm.
2. Deviation angle function with two-sided Snell refraction and total reflection test.
3. Scenario A: deviation for red (656 nm) and violet (405 nm), splitting computed.
4. Scenario B: source spectra (Planck, fluorescent, sodium) through prism; peak detection for classification (continuum vs. lines) plus coverage fraction.
5. Scenario C: deviation angle over incidence 30°–80°; numerical minimum vs. analytic minimum-deviation formula; total reflection boundary.

Results in `prismen_results.json`. Plot as `prismen_szenen.svg` (four subplots: dispersion curve, deviation per colour, minimum deviation, spectrum band).

10. Result

10.1 A dispersion

Quantity	BK7 crown	SF11 flint
n at 656 nm (red)	1.51433	—
n at 405 nm (violet)	1.53020	—
Δn (violet − red)	0.01587	0.06615
Angular splitting	1.39°	14.82°
Assessment M1	**refuted**	(stronger)

10.2 B source spectra (through BK7 prism)

Source	Peaks	Coverage	appears as
Incandescent 2700 K	0	92.6%	broad continuous band
Fluorescent	4	90.1%	**several discrete lines** (Hg)
Sodium vapour	1	3.7%	**single narrow line**
Assessment M1			**refuted**

10.3 C minimum deviation (BK7, 589 nm)

Quantity	Value
Minimum deviation numerical	38.643°
Minimum deviation analytic	38.641°
Incidence angle at minimum	49° (symmetric)
Total reflection below	30°
Assessment M1	**refuted**

Plot: `prismen_szenen.svg`.

11. Assessment

M1 (“refraction is colour-independent”) is refuted in all three scenarios. The module thereby closes the optics colour cluster by reinterpreting dispersion from disturbance (Module 05) to tool (spectroscopy).

Scenario A quantifies the dispersion. The refractive index of BK7 is 0.016 higher at violet than at red — an apparently small difference, but it produces an angular splitting of 1.39° (well visible). For the strongly dispersive flint glass SF11 the difference is 0.066, four times larger, the splitting reaches 14.8°. This explains why high-quality spectroscope prisms are made of flint glass: more dispersion = better spectral separation. It also explains why Module 05 (Lenses) had chromatic aberration as a problem — the same effect, different assessment depending on the goal.

Scenario B is the direct spatial confirmation of Module 07. The prism makes the spectrum visible: the incandescent shows a continuous rainbow band (92.6% of the visible range with energy, no sharp peaks), the fluorescent shows four sharp mercury lines as peaks over a weak phosphor background, sodium shows a single line at 589 nm (only 3.7% coverage). This is exactly the operating principle of every spectroscope and the historical way in which the spectral lines were discovered at all. Fraunhofer found dark lines in the solar spectrum in 1814 (absorption lines); Kirchhoff and Bunsen recognised in 1859 that every element has characteristic lines — the birth of spectral analysis and thereby of astrophysics (star spectra reveal the chemical composition).

Scenario C refutes the notion of a fixed deviation on a third level: even for a single wavelength the deviation angle is not constant but depends on the incidence angle and has a **minimum** at symmetric passage (ray goes symmetrically through the prism). The numerical minimum deviation (38.643°) agrees with the analytic formula (38.641°) to two thousandths of a degree — a nice validation. The minimum-deviation method is historically the most accurate way to measure the refractive index of a prism. At too shallow incidence (below 30°) total reflection occurs at the exit face, the light does not get through at all.

Connection to previous modules: - **Module 05 Lenses (chromatic aberration):** the same dispersion $n(\lambda)$, there as an image defect, here as a spectral tool. The achromatic doublet (crown + flint) is the bridge — it combines both glasses to cancel the dispersion. - **Module 07 Light Sources:** the source spectra that Module 07 treated numerically are here made spatially visible. - **Module 09 Colour Mixing:** the prism produces pure spectral colours; Module 09 showed that mixed colours (e.g. monitor yellow) are precisely not spectral colours. Prism and monitor are complementary. - **Module 01 Double Slit / diffraction grating:** the grating decomposes light through interference instead of refraction — complementary spectroscopy principle.

12. Next test

Module 10 Mirrors as a possible next step: reflection instead of refraction, imaging laws, spherical aberration in concave mirrors. Or **rainbow in nature** as a deepening of Module 06: dispersion plus total reflection in water droplets, primary and secondary rainbow, Alexander's dark band.

Possible extension Module 06 v0.2: diffraction grating in direct comparison to the prism (resolution, order, overlap), prism spectrometer with wavelength calibration, Fraunhofer lines in the solar spectrum.

Appendix A — Cross-references

- Practice explanation: `PRAXIS-Prismen-EN.md` (follows)
- Companion paper: `BEGLEITPAPIER-Prismen-EN.md` (follows)
- Tool: `REGENBOGEN.html` (follows)
- Code: `prismen_simulation.py`
- Plot: `prismen_szenen.svg`
- Result data: `prismen_results.json`
- Predecessor modules: Module 05 Lenses (chromatic aberration), Module 07 Light Sources (source spectra)
- Related modules: Module 09 Colour Mixing (spectral colours), Module 01 Double Slit (diffraction grating)

Appendix B — External stocktaking

- **Hecht (2017)** *Optics*, 5th ed. — standard reference, dispersion and prisms.
- **Born & Wolf (1999)** *Principles of Optics* — Sellmeier, dispersion theory.
- **Newton (1704)** *Opticks* — historical prism experiments.
- **Fraunhofer (1817)** — discovery of spectral lines.
- **Kirchhoff & Bunsen (1860)** *Chemical Analysis through Spectral Observations* — spectral analysis.
- **PhET "Bending Light"** — didactic refraction simulation.

What the workshop note adds: three contrasting scenarios in falsification format; the explicit reinterpretation of dispersion from disturbance (Module 05) to tool; real Sellmeier numerics with two glass types; the bridge to historical spectroscopy; connections to modules 05, 07, 09, 01.

Appendix C — Sources

- Hecht, E. (2017). *Optics*, 5th ed. Pearson.
- Born, M.; Wolf, E. (1999). *Principles of Optics*, 7th ed. Cambridge University Press.
- Newton, I. (1704). *Opticks*. London.
- Fraunhofer, J. (1817). Determination of the refractive and colour-dispersing power of different glasses. *Denkschr. Bayer. Akad. Wiss.*
- Kirchhoff, G.; Bunsen, R. (1860). Chemical Analysis through Spectral Observations. *Ann. Phys.* 186:161.
- SCHOTT (2023). *Optical Glass Data Sheets* (BK7, SF11 Sellmeier coefficients).

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