Contents

Acknowledgments

This list of errors and amendments refer to the first edition of the textbook "Optical Devices in Ophthalmology and Optometry: Technology, Design Principles and Clinical Applications" by Michael Kaschke, Karl-Heinz Donnerhacke and Michael Stefan Rill which was published by Wiley-VCH Verlag GmbH & Co. KGaA, Weinheim in 2014. We would like to acknowledge all valued readers who have carefully worked with our book and reported errors, typos and also suggestions for modifications and clarifications. We have compiled all these in the following list which will allow the readers of our book to treat the topics correctly and to avoid misunderstandings. Herewith, we would like to motivate also all readers to report any mistakes or non-clearly described passages in the text by email. In this case, please write a non-formal email at michael.kaschke@zeiss.com or michael.rill@zeiss.com. Please also visit our authors' website http://www.kaschke-medtec.de/OOO_Book.html.

The authors

1
Structure and Function

2
Optics of the Human Eye

3
Visual Disorders and Major Eye Diseases

Problems to Chapters 1–3

- **Problem PI.5 "Eye length"** (Page 73):
  A small variation of an emmetropic eye's axial length ΔL_{eye} with a refractive power of $\mathcal{D}'_{\mathrm{eye}}$ means a change of refraction by ΔA_{far}. We may approximate this change with

$$\Delta A_{\mathrm{far}} = -\Delta\mathcal{D}' \approx -\frac{\Delta L_{\mathrm{eye}}\,(\mathcal{D}'_{\mathrm{eye}})^2}{n} \tag{3.12}$$

1. Derive Eq. (3.12).
2. Verify the following statement for an emmetropic Gullstrand Eye with $\mathcal{D}'_{\mathrm{eye}} = 60$ D and $n = 1.336$: The variation of the eye length by ± 0.37 mm changes the eye's refraction by approximately ∓ 1 D.

4
Introduction to Ophthalmic Diagnosis and Imaging

5
Determination of the Refractive Status of the Eye

6
Optical Visualization, Imaging, and Structural Analysis

- **Section 6.1.1 "Optics of a Single Loupe"** (Page 149, Table 6.1):

  Table 6.1 Parameter sets of aspheric magnifier loupes (see also Problem P6.1). $\mathcal{D}_{\rm L}$ denotes the refractive power of the loupe, $\beta_{\rm L}$ the loupe magnification, $\beta_{\rm L,nominal}$ the nominal loupe magnification, s the object distance, $L_{\rm LP}$ the distance between the principal points of the eye and loupe, $d_{\rm L}$ the lens diameter, and $d_{\rm fov}$ the field of view. Courtesy of Carl Zeiss.

		Optimum working condition				
$\mathcal{D}_{\rm L}$ (D)	$\beta_{\rm L,nominal}$	$\lvert s\rvert$ (mm)	$L_{\rm LP}$ (mm)	$\beta_{\rm L}$	$d_{\rm L}$ (mm)	$d_{\rm fov}$ (mm)
6	1.5	145	185	2.1	100	90
8	2.0	110	220	2.7	85	50
12	3.0	70	210	3.5	70	30
16	4.0	55	130	3.25	60	30
20	5.0	40	90	3.1	55	28

- **Section 6.1.1 "Optics of a Single Loupe"** (Page 149, Line 3):
  The often specified nominal magnification of a loupe

  $$\beta_{\rm L,nominal} = \frac{\mathcal{D}_{\rm L}}{4\rm D} \tag{6.2}$$

  is only valid if the reference viewing distance $-s_{\rm ref}$ equals the typical near viewing distance $s_{\rm nv} = 25$ cm …

- **Section 6.2.2 "Functional Principle", Paragraph "Stereoscopic depth perception"** (Page 158, Line 5):
  For a human eye without visual aids and the typical near viewing distance $s_{\rm nv} = 250$ mm, it is given by (see Eq. (2.19))

  $$\Delta L_{\rm eye} = \frac{\varepsilon_{\rm min}\, L_{\rm eye}^2}{\rm PD} = 45\ \mu\rm m\ , \tag{6.14}$$

  where $\varepsilon_{\rm min} = 10''$ is the minimum stereo angle for photopic vision and PD the interpupillary distance.

- **Section 6.2.3.2 "Technical Optics: Chromatic Aberration of Objective Lenses"** (Page 163, Line 9):
  By setting $\mathrm{d}n_{\mathrm{L1}} = n_{\mathrm{L1}}(\text{blue}) - n_{\mathrm{L1}}(\text{red})$ and, similarly, $\mathrm{d}n_{\mathrm{L2}} = n_{\mathrm{L2}}(\text{blue}) - n_{\mathrm{L2}}(\text{red})$, we obtain

$$\frac{K_{\mathrm{L1}}}{K_{\mathrm{L2}}} = \frac{n_{\mathrm{L2}}(\text{blue}) - n_{\mathrm{L2}}(\text{red})}{n_{\mathrm{L1}}(\text{blue}) - n_{\mathrm{L1}}(\text{red})} \ . \tag{6.23}$$

- **Section 6.3.1.1 "Functional Principle"** (Page 180, Figure 6.22):

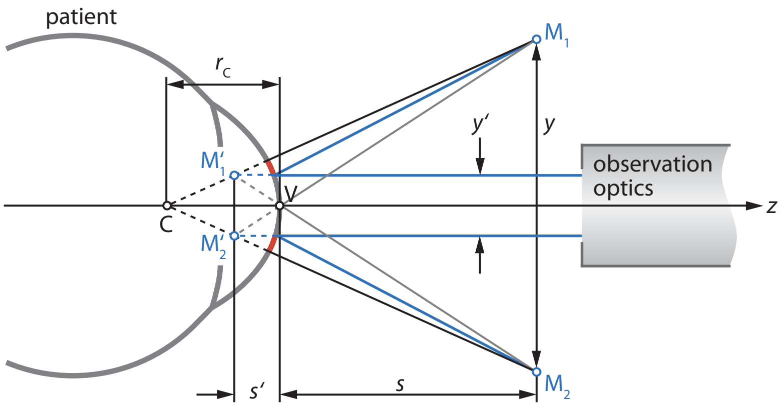

Figure 6.22 Measuring principle of a keratometer. M_1 and M_2 are test mires separated by a distance of y. M_1' and M_2' represent their corresponding images which are separated by a distance of y'. s is the distance between the corneal vertex V and the plane which contains both test mires, and s' is the distance from the corneal vertex to the plane which contains the test mire images. r_{C} and point C denote the corneal radius of curvature and the center of curvature, respectively. For the measurement, only two small, separated, usually circular segments (red) of the corneal surface are used. Adapted from [21].

- **Section 6.3.1.1 "Functional Principle"** (Page 180, Line 1):
  With $f' = r_{\mathrm{C}}/2 = \overline{CV}/2$ and the assumption $y \gg y'$, we obtain ...

- **Section 6.3.1.3 "Optoelectronic Keratometer"** (Page 186, Figure 6.26):

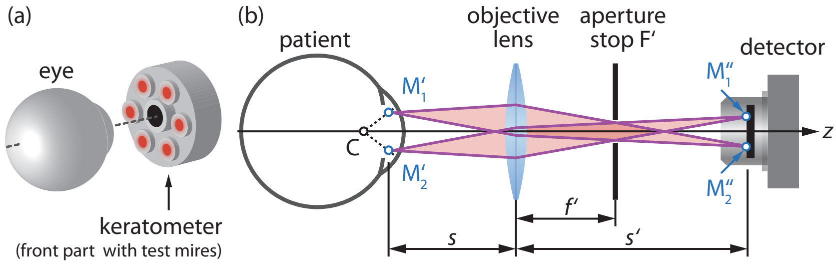

Figure 6.26 (a) Arrangement of illuminating light sources in the optoelectronic keratometer ZEISS IOLMaster® from the patient's point of view. (b) Ray diagram of the observation path in an optoelectronic keratometer. s is the distance between the test mire images M_1' and M_2' and the objective lens. s' is the distance between the objective lens and the mire images M_1'' and M_2'' projected onto the detector (CCD camera). An aperture stop is located at the image-side focal point F' of the objective lens (with focal length f'). Adapted from [21].

- **Section 6.6.3 "Indirect Ophthalmoscope", Paragraph "Magnification"** (Page 232, Line 3):
Hence, *for an emmetropic eye*, the magnification of an indirect ophthalmoscope is given by

$$\beta = -\frac{\mathcal{D}_{\mathrm{eye}}}{\mathcal{D}'_{\mathrm{oph}}} \quad , \tag{6.73}$$

where the negative sign …

- **Problem P6.1 (2) "Loupes"** (Page 267, Line 2):
Calculate the magnification of a loupe which consists of a thin lens with a focal length of $f' = 25$ mm.

- **Problem P6.2 "Stereoscopic vision"** (Page 268, Line 2):
He uses a *binocular* telescope with $8\times$ magnification whose objective *lenses are separated by a distance of* 115 mm.

- **Problem P6.4 "Achromatic design"** (Page 268, Table 6.9):

Table 6.9 Data of optical glasses. The refractive indices are given for the wavelengths 486 nm, 587 nm, and 656 nm. ν_d denotes the Abbe number. Data taken from [9].

Type of Glass	$n(486\,\text{nm})$ n_F	$n(587\,\text{nm})$ n_d	$n(656\,\text{nm})$ n_C	ν_d
N-FK51A	1.490 56	1.486 56	1.484 80	84.47
N-SF6	1.827 83	1.805 18	1.796 08	25.36
K-7	1.517	1.511 12	1.508 54	60.41
N-KZFS11	1.648 28	1.637 75	1.633 24	42.41

- **Problem P6.4 (2) "Achromatic design"** (Page 269, Line 1):
  How large is the distance of the *yellow* ($\lambda = 587\,\text{nm}$) from the blue-red ($\lambda = 486\,\text{nm}/\lambda = 656\,\text{nm}$) image plane (secondary chromatic aberration)? How large is the distance between the red and *yellow* image plane for a simple lens made of the glass K7?

- **Problem P6.5 "Apochromatic design"** (Page 269, Line 7):
  ... with the Sellmeier coefficients B_i and C_i given in Table 6.10. C_i are given in μm^2. In Eq. (6.81), the wavelength λ needs to be inserted in µm.

- **Problem P6.10 "Principle of topometry"** (Page 271):
  Approximate *the surface of* an optical system *as a sphere with* a radius of 25 mm. Then, superimpose on this system a cylindrical optical system with an axis inclined by 30° with respect to the vertical line (y-axis) and an additional radius of 85 mm.

  1. Calculate *(numerically-graphically)* a topometric image for an exactly axial alignment. Assume reasonable radii and reasonable stripe distances for the rings of the Placido disk.
  2. How does this image change if the topometry system is tilted by an angle α?
  3. Replace the spherical lens with a parabolic aspherical lens, whereby the radius of curvature is equal to the radius of the spherical lens. How does the topometric image change? *What statement can be made with regard to the distance between the rings in the camera plane?*

7
Optical Coherence Methods for Three-Dimensional Visualization and Structural Analysis

- **Section 7.4.1 "Theory of Time-Domain OCT – Axial Resolution"** (Page 303, Line 10):
  For a Gaussian spectral distribution

$$\sigma(\omega) = \frac{1}{\sqrt{2\pi\Delta\omega}} \exp\left(-\frac{(\omega-\omega_0)^2}{2(\Delta\omega)^2}\right) \tag{7.35}$$

  with bandwidth $\Delta\omega$ related to the spectral bandwidth $\Delta\lambda(\mathrm{FWHM})$ via …

- **Section 7.4.2 "Theory of Frequency-Domain OCT"** (Page 307, Line 1):
  With refractive index n_S, normalized coordinates $\hat{z}_\mathrm{S} = 2n_\mathrm{S}z_\mathrm{S}$, and the Fourier transform (A104), we find …

- **Problem P7.2 "Autocorrelation function, spectral density, and coherence length"** (Page 338):
  Calculate the autocorrelation function $\mathcal{G}$, the spectral density $\sigma(\omega)$, and coherence length L_c for various pulse forms and spectral distributions:

  1. Gaussian pulse
  2. Rectangle pulse
  3. sech^2 pulse
  4. Lorentz spectrum

  Use the definitions for $\mathcal{G}(\Delta t)$ and $\sigma(\omega)$ as given in Eqs. (A111) and (A109), respectively. For the coherence length as well as the spectral density use appropriate definitions, such as the full width at half maximum (FWHM), second momentum of a normalized function, or second momentum of a squared normalized function.

- **Problem P7.3 "Swept-source OCT"** (Page 339):
  How would you design a 1050 nm swept-source OCT with variable sweep rates up to 500 kHz and a tunable range of 100 nm for the various applications?:

  1. High speed/high resolution/small "imaging" depth (e.g., used for retinal scans)
  2. Medium speed/medium resolution/medium "imaging" depth (e.g., used for scans in the anterior chamber)

3. Low speed/medium resolution/ultra-deep “imaging” depth (e.g., used for whole-eye scans)

Determine relevant parameters for sweep rate, bandwidth, SNR, measuring time per axial scan, and so on.

- **Problem P7.7 “Theory of FD-OCT”** (Page 339):

1. Use a mathematical software tool (e.g., MATLAB or MathCad) to simulate an FD-OCT spectrum resulting from the reflections of the 4 major interfaces of the anterior segment of the eye (assumed to be δ functions in space). Assume a Gaussian pulse of spectral bandwidth for various broadband light sources, for example, SLD with $\lambda_0 = 1300$ nm and 200 nm bandwidth, titanium:sapphire laser with $\lambda_0 = 800$ nm and 70 nm bandwidth, and/or SLD with $\lambda_0 = 1050$ nm and 100 nm bandwidth. What can you say about the required resolution of the spectrometer and the dynamic range?
2. Overlay on the simulated spectra a simulated white noise spectrum. Then, Fourier transform the simulated results to obtain an A-scan of the anterior eye segment. What do you observe?

- **Problem P7.8 “Theory of SS-OCT”** (Page 340):
Let us consider an SS-OCT with 1050 nm center wavelength and a sawtooth-like sweep.

1. Simulate the detector signal for a typical sweep rate of 200 kHz and various arm length mismatches (100 µm, 1 mm, 10 mm).
2. How does the result changes when the direction of the sweep is reversed? How, if the sweep rate is reduced to 50 kHz?
3. Use a mathematical software tool (e.g., MATLAB or MathCad) to simulate the SS-OCT spectrum resulting from the reflections of the 4 major interfaces of the anterior eye segment (assumed to be δ functions in space). Use 1050 nm as a center wavelength and a sawtooth-like sweep with 200 kHz. Then, Fourier transform the simulated results to obtain an A-scan of the anterior segment of the eye.

Compare with the results of Problem P7.7.

- **Problem P7.14 “Intraocular lens power determination with biometry”** (Page 341):
Estimate the uncertainties in the determination of the IOL power which result from uncertainties in the measurement of the biometric parameters:

1. eye length uncertainty: 10 µm and 50 µm
2. uncertainty of the anterior chamber depth: 10 µm and 50 µm
3. corneal radius

Which other factors influence the calculated power of an IOL?

8
Functional Diagnostics

9
Laser–Tissue Interaction

- **Section 9.4.4.1 "Laser-Induced Optical Breakdown in Biological Tissue"** (Page 386, Figure 9.8):

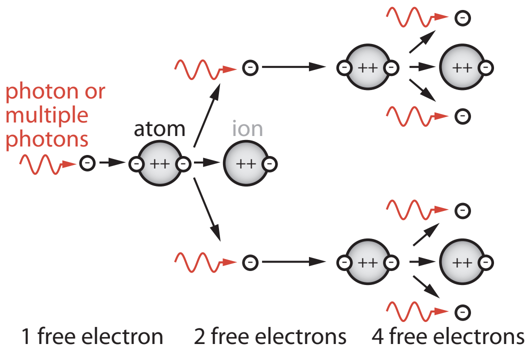

Figure 9.8 Scheme of an electron avalanche ionization. The electroncs are represented by particles with a minus sign, and ions are indicated by "++". Adapted from [3].

10
Laser Systems for Treatment of Eye Diseases and Refractive Errors

A
Basics of Optics

B
Basics of Laser Systems

- **Problem PB.3 (1) “Gaussian laser beams”** (Page 584, Line 3):
  What is the condition for an *afocal* Galilei telescope?

- **Problem PB.3 (2) “Gaussian laser beams”** (Page 584, Line 2):
  … by using a *Galilei* telescope which consists of thin lenses …