

Exam - Optical Engineering

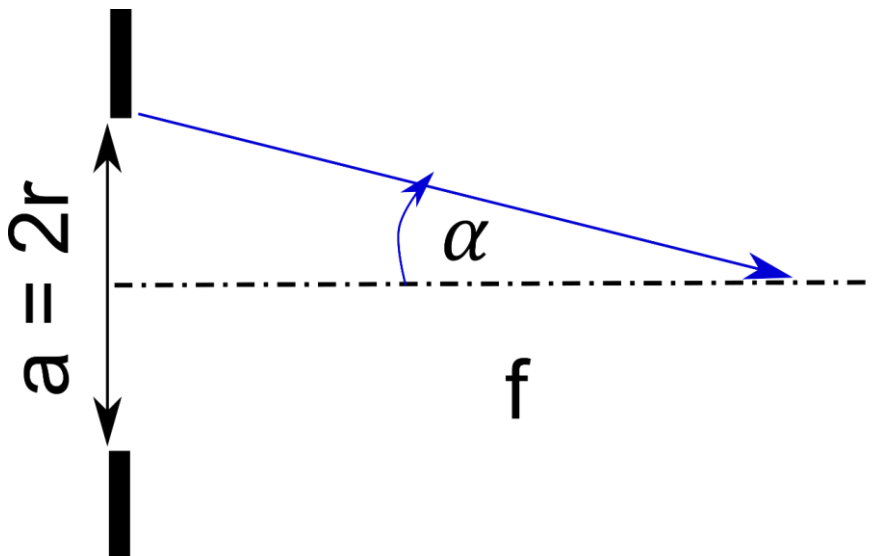
Mandatory Task 1: Reflection and Refraction

A ray travelling through air ($n_a = 1$) hits the surface of the water ($n_w = 1.33$) with an angle of 41.81° with respect to the surface normal.

- Calculate the angles for transmitted and reflected rays. (2 Points)
- Draw schematically the diagrams for dependence of transmitted and reflected power on the angle of incidence for both s- and p-polarization. Mark the Brewster angle and explain what happens there. (4 Points)
- What is total internal reflection and under what conditions does it happen? (2 Points)

Mandatory Task 2: Numerical aperture

Numerical aperture is an important property of the light that is transmitted by an optical system. It determines the lateral and axial resolution and at the same time is an indicator about the complexity of the optical system. Numerical aperture is defined as $NA = n \cdot \sin(\alpha)$, where n is the refractive index of the surrounding medium and α is the half of the opening angle.



Usually, the NA can be determined without measuring the angle of the light cone by $NA \approx \frac{r}{f}$.

- What is the approximation behind and when is it valid? (2 Point)
- Calculate the half of the opening angle for an air objective with a numerical aperture of 0.65. (1.5 Points)
- What is the theoretical maximum numerical aperture for an air objective? Why can't air objectives reach it in practice? (2 Points)
- What is practically done so that numerical apertures can be larger than 1.0, e.g. $NA = 1.45$? (1 Point)

Name:
Exam date: 28.07.2022

Matriculation Number:
Sheet Number:

Selection Tasks. You have to pick one of the options below. If you chose to solve both tasks, only the higher scoring one will be counted.

Selection Task: Option 1 - Diffraction and Imaging

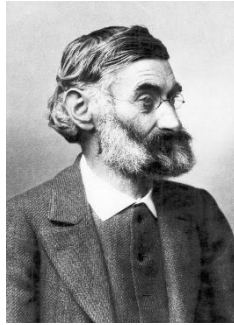
- a) What is diffraction of light? Explain diffraction at a grating and an aperture using Huygens principle. How are 1st and -1st diffraction orders created? (3 Points)
- b) How are the Fourier Transform and the imaging process of an optical system related? (1 Point)
- c) What is a point spread function (PSF) physically and what mathematically? How is it related to the resolution of a system and why does a realistic system always have a limited resolution? (4 Points)
- d) Sketch the perfect PSF along the lateral and axial coordinates around the focus for a circularly symmetric system. Which are the main parameters that determine the extent of an ideal PSF? From the ideal PSF, derive/explain the Rayleigh resolution limit. (2 Points)

Selection Task: Option 2 - Optical Aberrations and Image Quality

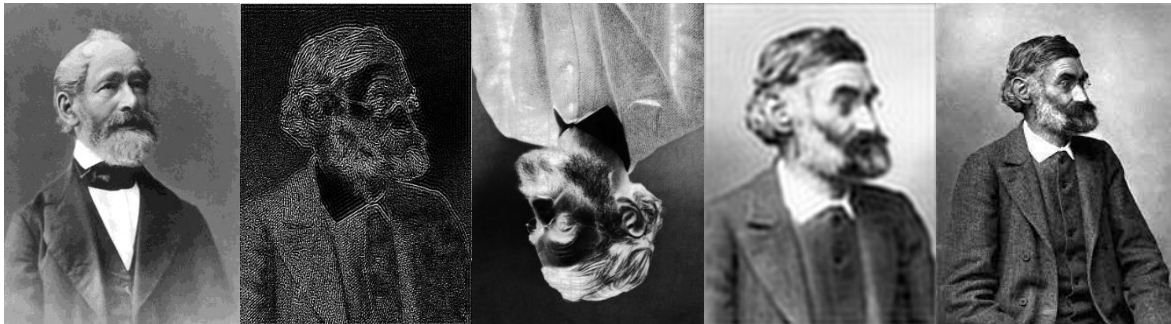
- a) How are optical aberrations described in the ray and how in the wave picture? (2.5 Points)
- b) Which are the primary aberrations? Briefly sketch and describe each one of them. Why are tip, tilt, and defocus not considered real aberrations? (5 Points)
- c) Describe one of the most commonly used image quality criteria. (1 Point)
- d) What is the so-called diffraction-limited performance of an optical system? How is it defined according to (i) Rayleigh, (ii) Maréchal, (iii) and Strehl? (1.5 Points)

Mandatory Task 3: Multiple choice on OE

I) An image of the German physicist and mathematician Ernst Abbe has been **low pass** filtered, regarding its **spatial frequencies** in Fourier space. Which one of the following images is the low pass filtered one (1 Point)? For 0.25 bonus points each: What transformations are the other images showing?



Original



a

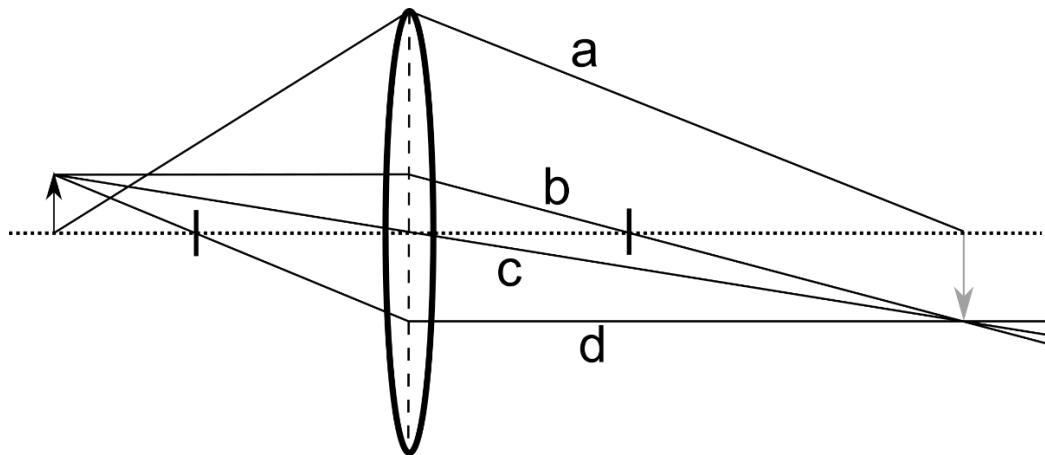
b

c

d

e

II) Below is a sketch of the imaging principle using geometrical optics. Which of the beams (object on the left, image on the right) denotes the marginal ray (1 Point)? For 0.25 points each: What are the other beams?



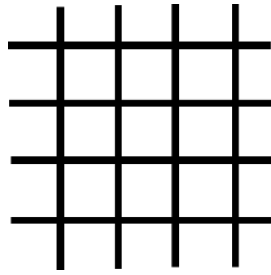
a

b

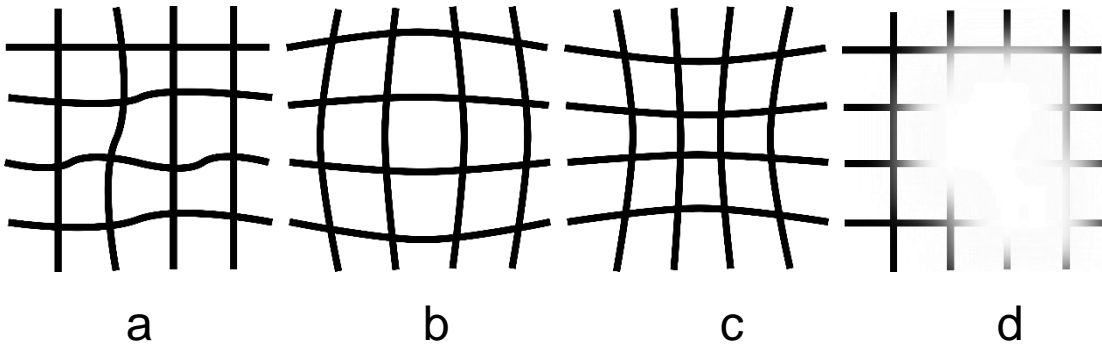
c

d

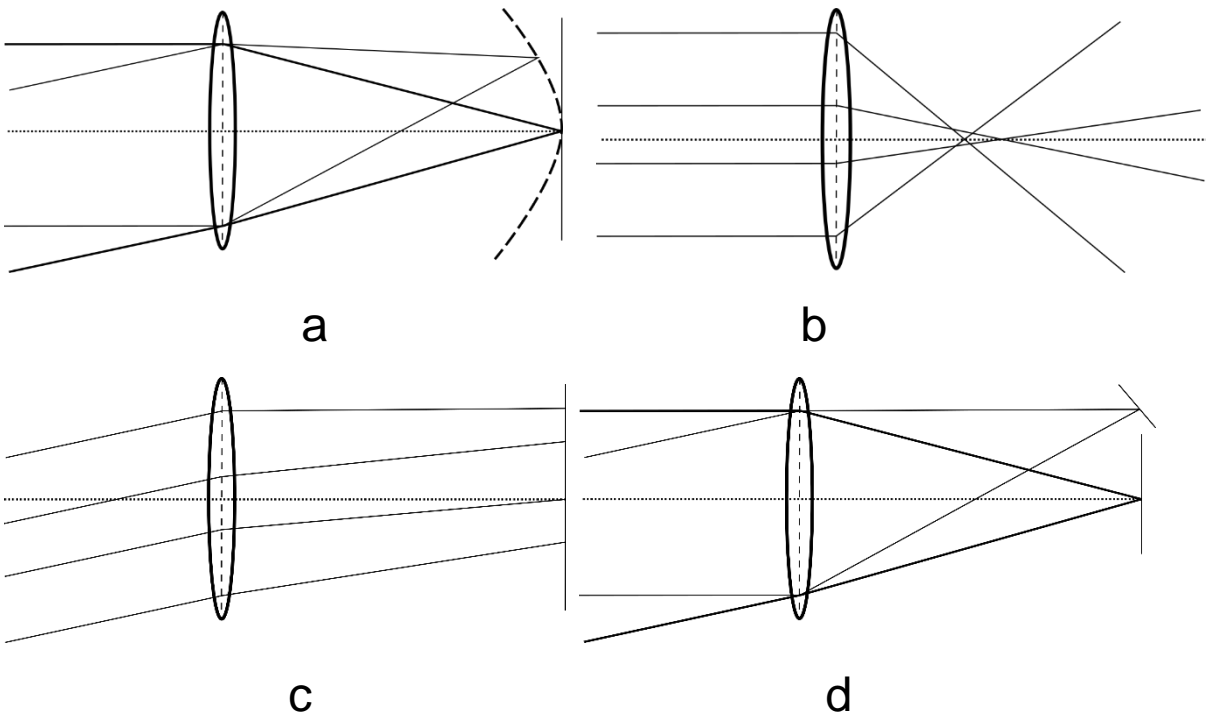
III) The following structure has been imaged but with different errors in the system.



Denote the one that has been clearly affected by barrel distortion (1 Point)! For 0.25 points each: What are the other distortions caused by?



IV) Shown here are sketches of different aberrations. Denote the one that is not called a "real aberration". (1 Point)

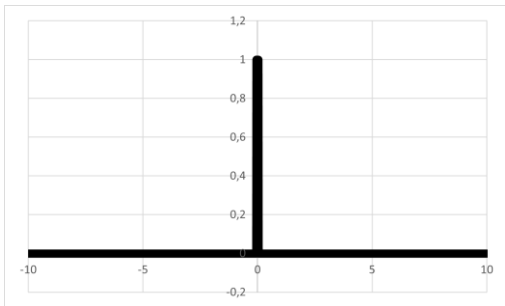


For half a point each, what are the other aberrations?

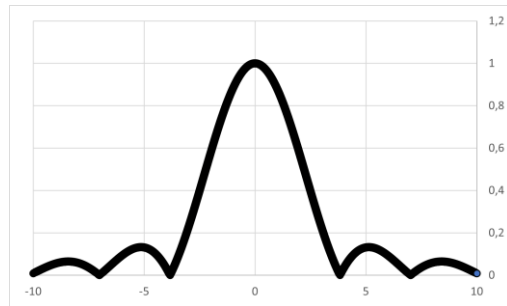
Name:
Exam date: 28.07.2022

Matriculation Number:
Sheet Number:

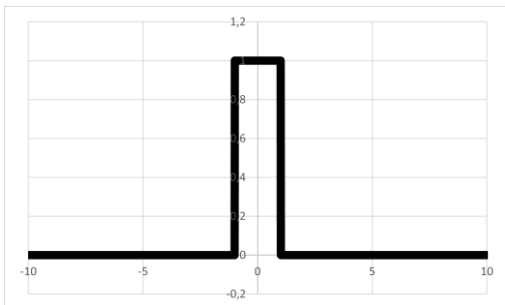
V) Which of the following graphs describes best the **intensity** of the Airy pattern? (1 Point)



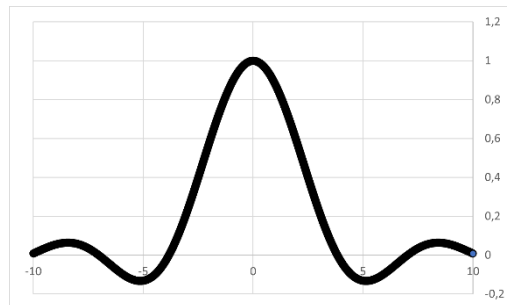
a



b



c



d

VI) The dispersion of light when it passes through a prism shows that (1 Point)

- a) the prism contains many narrow, equally spaced slits
- b) all wavelength components of the light are reflected differently
- c) all wavelength components of the light are refracted differently
- d) all wavelength components of the light are refracted equally
- e) the speed of light in a vacuum is a constant

VII) A human eye employs a lens to form images (1 Point)

- a) converging virtual
- b) converging real
- c) virtual virtual
- d) diverging real
- e) diverging virtual

IX) What is the principle of fibre optical communication? (1 Point)

- a) Frequency modulation
- b) Population inversion
- c) Total internal reflection
- d) Doppler Effect
- e) Scattering

Name:
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Sheet Number:

Extra Task 6: Bonus question for additional points

We are sure that You are well prepared and have learned a lot of content of the OE lecture – some of which may did not make the cut for the exam. For an additional 4 Points explain something from the lecture or the seminar that hasn't been part of the exam questions. Alternatively answer the following question with a good explanation: The mirror image is inverted from left to right and vice versa. Why isn't it inverted in upwards and downwards direction.