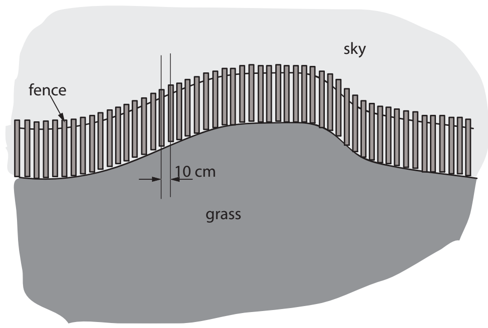
Exam SK2330 Optical Design 2010-05-25

No devices that allow for communication with the outside world, or that would permit installation of commercial optical design software, are permitted (i.e., no computers). Any other material such as books, notes, and calculators may be used.

Solutions should be well outlined and explained, and figures used when needed. Correct answers without explanations give 0p.

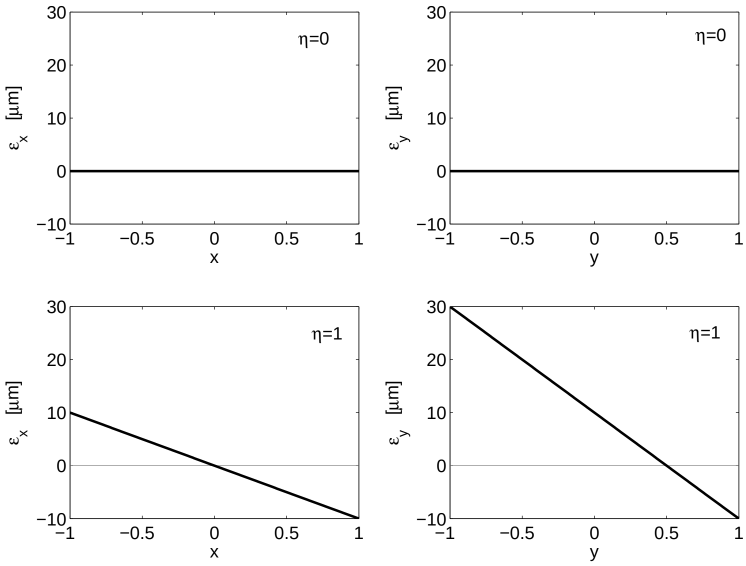
Grading: 0–8p F, 9–11p Fx, 12–14p D, 15–18p C, 19–21p B, 22–24p A

1. Sarah wants to take a photograph of a hill. Over the hill, outlined against the sky, runs a fence consisting of vertical planks with spacing in between, as illustrated in the figure below. She estimates that the contrast between the dark planks and the bright sky behind is around 0.8. The spacing between planks is 5 cm, and the distance to the fence is 500 m. Sarah wishes the planks to be visible in her photograph, with reasonable contrast (around 0.4). She uses a photographic objective of standard focal length 35 mm, which we assume to be diffraction limited. Estimate the smallest aperture size she can use. Outline any assumptions you make. (5p)



2. Oscar wishes to focus the light from a small, distant white-light source onto a screen, with no longitudinal chromatic aberration. The simplest way would be to use an achromatic doublet, but he cannot find one. Instead, as he searches the lab, he comes across two singlet lenses: one made from BK7 of focal length +100 mm, and one made from SF6 of focal length -100 mm. He decides to combine those two lenses to produce the focus. The lenses are assumed to be thin. BK7 has refractive index $n = 1.51679$ and Abbe number $V = 64.17$, while SF6 has $n = 1.80516$ and $V = 25.44$.
   a) How can he do this? Sketch the system he will be using, clearly indicating where the positive lens and the negative lens are placed and where the focus is formed. (3p)
   b) Calculate the distance between the two lenses. (2p)
   c) Find the effective focal length of this system! (1p)

3. The transverse ray aberrations ϵ_x (sagittal) and ϵ_y (tangential) of a lens in monochromatic illumination are given in the figure below as functions of normalized pupil coordinates x and y. The graphs are on-axis ($\eta = 0$) and for full image height ($\eta = 1$). The lens has focal length 300 mm and aperture radius 20 mm. The system has only third-order aberrations, and the object is at infinity.



a) Explain which aberrations are present in this system, and which are not. Motivate your answer! (2p)
b) Calculate the relevant wavefront aberration coefficients. (2p)

4. A small on-axis object is imaged 1:1 using a thin lens of refractive index 1.5 in monochromatic light. Two lenses of the same focal length and aperture size are available: an equi-convex lens and a plano-convex lens.
a) Which are the relevant aberrations? Explain your answer. (1p)
b) Which lens will give the smallest aberrations? How many times better is the result, compared to using the other lens? (3p)

5. Even a plane glass plate can introduce aberrations into a beam. When light passes through a plate of thickness d and refractive index n, it can be shown that aberrations are introduced to the beam, and that the Seidel coefficients are

$$S_I = -u^4 d \frac{n^2-1}{n^3}$$
$$S_{II} = -u^3 \bar{u} d \frac{n^2-1}{n^3}$$
$$S_{III} = -u^2 \bar{u}^2 d \frac{n^2-1}{n^3}$$
$$S_{IV} = 0$$
$$S_V = -u \bar{u}^3 d \frac{n^2-1}{n^3}$$

where u is the marginal ray angle and $\bar{u}$ the principal ray angle. A camera objective is used to focus collimated monochromatic green light according to the figure below. Since two simultaneous focii are required, a beamsplitter at 45 degrees is placed between the objective and the screen. The beamsplitter is made from a 1 cm thick, flat plate of refractive index $n = 1.5$. The camera objective has numerical aperture $NA = 0.26$. For the beam that passes straight through the beamsplitter to form image (1), find the mathematical expression for the wavefront aberration and sketch two graphs showing the wavefront aberrations in the sagittal and tangential planes. Make sure the scales are correct. Assume the wave incident on the camera is plane, that the camera objective introduces no aberrations, and that paraxial theory applies. (5p)