OPT 300 Final exam

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This is the final exam for OPT 300. It is worth 22.2% of your final grade. Your response is due May 7, 2007 at 10:00AM. You may deliver your response on paper or via e-mail. Each of the numbered questions contribute equally to the grade. Your response should be an individual effort. You may e-mail me for hints, and I will share your question and my answer with the entire class. In some cases you may need to make assumptions or research typical values. In those cases please please state your assumption or research source. If you get stuck and need an answer (but not "solution") from a previous question to complete a later question, please contact me.

This exam contains 27 equally weighted individual questions spread over 4 problems. There are also 3 extra credit problems, so that you can earn up to a total of 111.11%.

Problem 1: Golden gate

You are visiting the Golden Gate bridge bringing a camera along which suffers from astigmatism. You are photographing the following scene and the optical axis of your camera points toward the center of the span.

1. Write the expression for the aberration caused by primary astigmatism.
2. How should you focus your lens to make the roadbed sharp?
3. How would you focus your lens to make the pylons sharp?
4. The vertical cables are called suspenders. Is it possible to bring all of the suspenders in sharp focus at the same time? Why (not)?
5. The image you see is recorded on a CCD chip 1/2 inch wide, and you are in an airplane 1 mile away. What is the focal length of your lens? (Assume a simple lens which generates an inverted image)
6. Repeat the calculation for the case when you are 10 miles away.

7. To your dismay you discover that your lens also suffers from primary (3rd order) and secondary (5th order) spherical. The primary coefficient is 1, and the secondary coefficient is -2 with the aperture diameter $D = 2$. Plot the aberration of rays as a function of aperture position $y \in [-1; 1]$. What is the largest ray aberration?
8. With the spherical aberration described above, would you choose to refocus the lens away from the paraxial focus to get a sharper image? Why or why not?
9. **Extra credit:** Discuss how you might in principle be able to estimate the distance to the golden gate and the focal length of your lens if you have intimate knowledge of the objects in the scene and their relative positions.

Problem 2: Sparrow

You are an avid bird watcher, with a particular fascination for the nesting and feeding habits of small birds.

1. What power telescope do you need to be able to detect that a sparrow is pulling a worm out of the ground 600 m away? (Suppose you need a resolution of 3 mm at the sparrow)
2. What is the minimum useful diameter of the objective lens so that diffraction patterns are not visible, and so that the exit pupil has a diameter of 5 mm?
3. What is the field of view in object space if it is $\pm 5°$ in image space?
4. What maximum image height does that correspond to at the sparrow?
5. If the telescope has a total length of 1 m, the focal length of the erecting lens is 5 cm, and you choose the working magnification of the erecting lens to be unity, what should be the focal lengths of the objective and eye lenses?
6. What should be the diameter of the erector lens to avoid vignetting?
7. What should be the diameter of the eye lens to get the field of view stated before?
8. **Extra credit:** How much will this telescope weigh (roughly) if you use glass with a density of 2.5 g/cm^3. Would you like a tripod with that?

Problem 3: Compound lens and ray tracing

Consider a system composed of three thin lenses. The first lens has a focal length of 10 cm. The second lens is located 20 cm to the right of the first lens and has a focal length of 5 cm. The third lens is located 15 cm to the right of the second lens and has a focal length of 20 cm. Think carefully about the original definition of the quantities asked for and trace rays to obtain what you need to answer the questions.

1. What is the effective focal length of the system?

2. What is the back focal length?

3. Where is the second focal point?

4. Where is the second principal plane?

5. What is the front focal length?

6. Where is the first principal plane?

7. Draw to scale the lens system, draw and label the principal planes, and draw and label the focal points.

8. **Extra credit:** Where is the image of an object located 100 cm to the left of the first lens, and what is the magnification?

Problem 4: Anti-reflective coating

1. Explain how an anti-reflective coating works.

2. What is the optimal index of refraction for a coating for a glass lens with index of refraction $n_{\text{glass}} = 1.69$ if the lens is in air?

3. Specify the optimal thickness of a magnesium-fluoride anti-reflective coating for this lens (The index of MgF_2 can be found in the text).

4. Plot the reflectivity with and without the coating for s-polarized light as a function of incidence angle.

5. Plot the reflectivity with and without the coating for p-polarized light as a function of incidence angle (you may use the same graph as in the previous question if you would like).