NAME ____

This is a 100-point homework project (practice exam), originally given as a take-home midterm exam. It emphasizes conceptual understanding of optical design principles and practical implementation in Zemax. Students were to use Geary and Greivenkamp textbooks and class materials, but not the internet or any people other than me (but you are welcome to discuss this homework assignment with other students).

Timing: A design report for this project is due by **5 pm on Tuesday, March 7**, 2017.

What to turn in: Your hand-written calculations and notes showing calculations and describing your design approach and results. Clearly indicate which Zemax file corresponds to each section of notes. Email me your Zemax files in a zip file.

The Problem:
You are to design a simple telephoto lens with the following first-order properties:

- Effective focal length = EFL = 120 mm
- Back focal distance = BFD = 50 mm
- Lens separation = t_{ab} = 40 mm
- Image space f/# = 10
- Field angles = 0°, 2.1°, 3°
- Wavelength = 0.587 μm (*d* light)

Design goal: maintain all first-order properties and achieve **rms spot sizes ≤ 20 μm**.

Exam questions:

1. (20 points)

a. Calculate the optical power of two thin lenses to achieve the stated EFL, BFD, and t_{ab}. Show your work and explain any assumptions (use and label separate sheets of paper).

b. Calculate the radii of curvature for your two thin lenses, assuming equiconvex or equiconcave elements made of BK7 glass.

2. (5 points) Calculate principal plane locations (ok to use equations instead of y-nu).

d = ___________ (distance from front surface of first lens to p)
d' = __________ (distance from back surface of last lens to p')

Sketch your lens to show locations of the lenses, focal points, and principal planes.

3. (5 points) Insert your thin-lens design into Zemax with the aperture stop located immediately before the first lens (thickness after stop = 0); save your file as *Telephoto_name1o1b.zmx*, where *name* is your last name. Use lens semi-diameters = 12.5 mm (i.e. 1-inch lenses commonly available in optics labs). Record the EFL and BFD listed in the Zemax *System* listing (make sure they are close to your target values).

EFL = ________________
BFD = ________________ (Zemax calls this the "back focal length")
f/# = __________________

4. (10 points) Insert thickness for your two lenses (use 3 mm for positive elements and 2 mm for any negative elements). Place a variable on the last lens surface curvature and optimize to restore your EFL and BFD while also maintaining t_{ab}. Verify that the "total track" (length) is less than the EFL.

Telephoto_name2o1b.zmx → *Telephoto1_name2o1a.zmx*.

Brief explanation of how you did this in Zemax:

Write down the values for the following first-order properties (from Zemax):
EFL = _______________
BFD = _______________
t_{ab} = _________________ (this is the distance between lens *a* and lens *b*)
Total track = __________ (< EFL for telephoto lens)

From Zemax, write down the following:

rms spot sizes: ______, ______, ______ μm (use "dithered," "centroid," "Airy disk")

Do these spot sizes meet your design goal yet? ______________

Which Seidel aberration is dominant? ___________________ (give its name)

List the values for the following Seidel aberration coefficients:
W_{040} = ________ units = _______
W_{131} = ________
W_{222} = ________

What do the ray fans and spot diagrams tell you? (briefly describe shape of ray fans and spots, and tell what the shapes indicate):

Additional comments:

5. (10 points) Place variables on the four lens surface curvatures and optimize to minimize spherical aberration and coma while maintaining first-order properties.

Telephoto _name3o1b.zmx → *Telephoto _name3o1a.zmx*

Briefly describe what occurred in this optimization cycle.

EFL = ________________
BFD = ________________
t_{ab} = __________________

rms spot sizes: ______, ______, ______ μm

Do these spot sizes meet your design goal? ___________

Which Seidel aberration is dominant? ___________ (give its name)
Is this different from before? __________
Why? (explain briefly the main reason):

List the values for the following Seidel aberration coefficients (ok to read from Zemax):

W_{040} = _________
W_{131} = _________
W_{222} = _________

What do the ray fans and spot diagrams tell you? (briefly describe shape of ray fans and spots, and tell what the shapes indicate):

Additional comments:

6. (10 points) Move the aperture stop into the space between the two lenses. Place a variable on the stop location, but constrain it to remain between lenses (be sure you constrain the total space between lenses at 40 mm). Also leave variables on the curvatures. Optimize for minimum spherical and coma while maintaining first-order properties.

Telephoto _name4o1b.zmx → *Telephoto _name4o1a.zmx*

Explain what you did and what happened:

EFL = ________________
BFD = ________________
t_{ab} = ___________________

rms spot sizes: _______, _______, _______ μm

Do these spot sizes meet your design goal yet? ________

Which Seidel aberration is dominant? ___________ (name)

List the values for the following Seidel aberration coefficients (ok to read from Zemax):

W_{040} = _________
W_{131} = _________
W_{222} = _________

Is this solution practical? ______________
Explain:

What do the ray fans and spot diagrams tell you? (briefly describe shape of ray fans and spots, and tell what the shapes indicate):

Additional comments:

7. (10 points) Remove the weights on spherical and coma, and insert TRAC (default merit function to minimize the rms spot size with respect to the centroid).

Telephoto _name5o1b.zmx → *Telephoto _name5o1a.zmx*

Explain what you did and what happened:

EFL = _______________
BFD = _______________
t_{ab} = _________________

rms spot sizes: ______, ______, ______ μm

Do these spot sizes meet your design goal yet? _______

Which Seidel aberration is dominant? __________ (name)

List the values for the following Seidel aberration coefficients (ok to read from Zemax):

W_{040} = ________
W_{131} = ________
W_{222} = ________

Is this solution practical? _____________
Explain:

What do the ray fans and spot diagrams tell you? (briefly describe shape of ray fans and spots, and tell what the shapes indicate):

Additional comments:

8. (10 points) Return the stop to its original location immediately in front of the first lens surface (distance from stop to lens = 0). Remove the variable from the stop location. Leave variables on the lens curvatures. Add a variable to t_{ab}, the separation between the two lenses. Constrain the lens separation to remain in the range 10 mm < t_{ab} < 60 mm. Continue to maintain the EFL and BFD.

Telephoto _name6o1b.zmx → *Telephoto _name6o1a.zmx*

Explain what you did and what happened:

EFL = ________________
BFD = ________________
t_{ab} = __________________

rms spot sizes: _______, _______, _______ μm

Do these spot sizes meet your design goal? ________

Which Seidel aberration is dominant? ___________ (name)

List the values for the following Seidel aberration coefficients (ok to read from Zemax):

W_{040} = _________
W_{131} = _________
W_{222} = _________

Is this solution practical? ______________
Explain:

What do the ray fans and spot diagrams tell you? (briefly describe shape of ray fans and spots, and tell what the shapes indicate):

Additional comments:

9. (10 points) Now let the BFD vary. Reoptimize with variables on the curvatures, lens separation (constrained to stay between 10 and 60), and BFD, while maintaining EFL = 120 mm.

Telephoto _name7o1b.zmx → *Telephoto _name7o1a.zmx*

Explain what you did and what happened. Comment on whether or not the resulting BFD and total track length are reasonable:

EFL = ________________
BFD = ________________
t_{ab} = __________________
Track length ___________

rms spot sizes: _______, _______, _______ μm

Do these spot sizes meet your design goal? ________

Which Seidel aberration is dominant? ___________ (name)

List the values for the following Seidel aberration coefficients (ok to read from Zemax):

W_{040} = _________
W_{131} = _________
W_{222} = _________

Is this solution practical? ______________
Explain:

What do the ray fans and spot diagrams tell you? (briefly describe shape of ray fans and spots, and tell what the shapes indicate):

Additional comments:

10. (10 points) Explore! See how small you can allow the f/# to become while still meeting the 20 μm rms spot size requirement. Everything but the EFL can change as long as the resulting system is practical and compact (track length approximately ≤ EFL).

Explain how you got your best result and how good it is:

How low could you go for the f/#? ___________

Remember: customers generally want "fast" optics, meaning small f/#.

Additional comments: