Name_______________________

Closed book; closed notes. Time limit: 120 minutes.
An equation sheet is attached and can be removed. Spare raytrace sheets are attached.
Use the back sides if required.
Assume thin lenses in air if not specified.
If a method of solution is specified in the problem, that method must be used.
Raytraces must be done on the raytrace form. Be sure to indicate the initial conditions for your rays.
You must show your work and/or method of solution in order to receive credit or partial credit for your answer.
Provide your answers in a neat and orderly fashion. No credit if it can't be read/followed.
Use a ruler or straight edge!
Only a basic scientific calculator may be used. This calculator must not have programming or graphing capabilities. An acceptable example is the TI-30 calculator. Each student is responsible for obtaining their own calculator.
Note: On some quantities, only the magnitude of the quantity is provided. The proper sign conventions and reference definitions must be applied.

Distance Students: Please return the original exam only; do not scan/FAX/email an additional copy. Your proctor should keep a copy of the completed exam.

1) (10 points) Design a Galilean telescope constructed out of two thin lenses in air. The telescope must have a magnifying power of 3X and a length of 75 mm.

f_{OBJ} = _________ mm f_{EYE} = __________ mm

2) (15 points) Design a spectacle lens for a patient with corneal astigmatism. The patient requires a lens that has powers of -4 D and -6 D in orthogonal meridians on the lens. The lens has an index of 1.5, and the shape of this thin lens in air is a meniscus. The concave spherical surface of the lens has a radius of curvature of 80 mm. The convex surface of the lens is toroidal producing the required power variation.

a) Determine the two principal radii of curvature for the convex surface of the lens.

b) What is the surface sag difference of the convex surface along the two principal meridians? Determine this sag at a radius of 20 mm from the surface vertex.

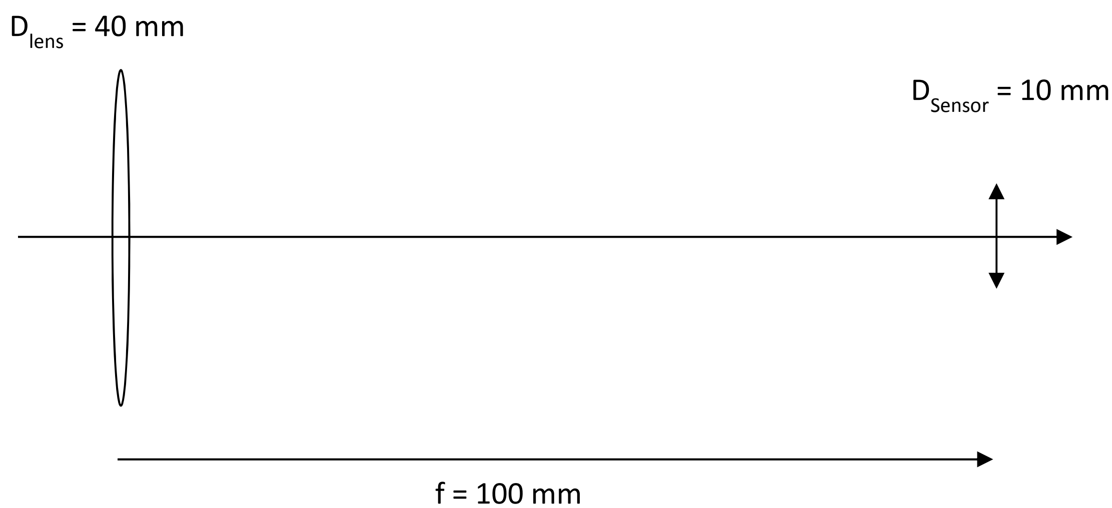
R1 = ________ mm R2 = _______ mm ΔSag = __________ mm

3) (15 points) As shown below, a 100 mm focal length thin lens is used to image an object at infinity. The lens has a diameter of 40 mm. The sensor used with the lens has a width of 10 mm (± 5 mm). The system stop is at the lens.

A right angle prism is to be inserted between the lens and the sensor. The exit face of the prism must be spaced 20 mm from sensor. The prism has an index of refraction of 1.5.

What is the smallest prism that can be used in the system with no vignetting? In other words, the system is unvignetted over the full width of the sensor.

Let H be the width of the face of the prism. You may consider this to be a one-dimensional problem and consider vignetting only in the plane of the paper.

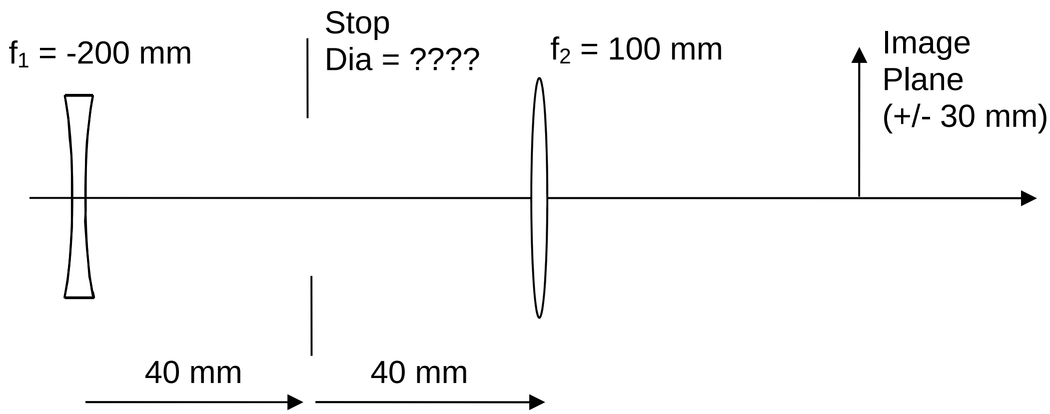


Continues…

Minimum Prism Size H = _____ mm

4) (25 points) The following diagram shows the design of an objective that is comprised of two thin lenses in air. The system stop is located between the two lenses.

The system operates at f/4.
The object is at infinity.
The maximum image size is +/- 30 mm.



Determine the following:
- Entrance pupil and exit pupil locations and sizes.
- System focal length and back focal distance.
- Stop diameter.
- Angular field of view (in object space).
- Required diameters for the two lenses for the system to be unvignetted over the specified maximum image size.

NOTE: This problem is to be worked using raytrace methods only. All answers must be determined directly from the rays you trace; for example, the FOV must be determined from a raytrace. Raytraces must be done on the raytrace form. Be sure to clearly label your rays on the raytrace form. A method of solution explaining your procedure and calculations must be provided. Calculations may NOT be done in the margins of the raytrace sheet. Gaussian imaging methods may not be used for any portion of this problem.

Entrance Pupil: ________ mm to the _______ of the first lens. D_{EP} = ________ mm

Exit Pupil: ________ mm to the _______ of the second lens. D_{XP} = ________ mm

System Focal Length = _________ mm Back Focal Distance = _________mm

Stop Diameter = _________ mm FOV = +/- _______ deg in object space

Lens 1 Diameter = _________ mm Lens 2 Diameter = _________ mm

Surface	0	1	2	3	4	5	6
f							
$-\phi$							
t							
y							
u							
y							
u							
y							
u							
y							
u							
y							
u							
y							
u							
y							
u							

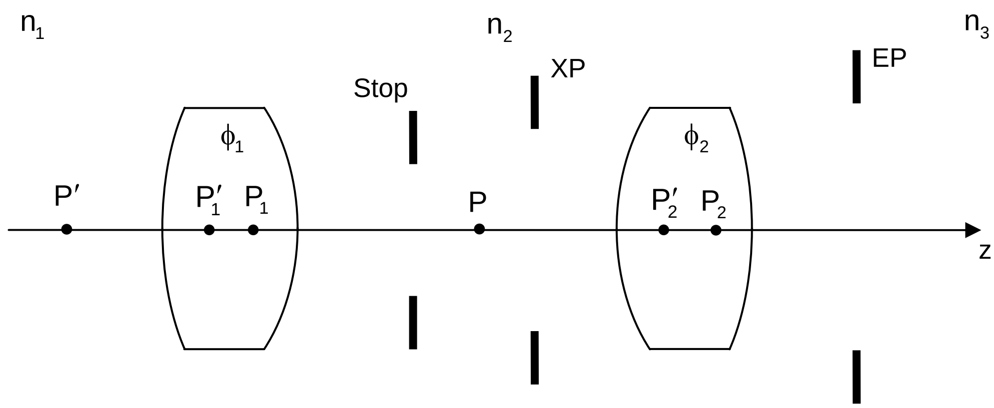
Continues…

Provide Method of Solution:

Continues…

Provide Method of Solution:

5) (10 points) An optical system is comprised of two elements separating indices of refraction n_1, n_2 and n_3. Subscript 1 designates element 1, subscript 2 designates element 2, and quantities without subscripts (EP, XP, P and P′) are associated with the total system.



Circle the index of refraction (and therefore the corresponding optical space) associated with each of the following:

EP:	n_1	n_2	n_3	XP:	n_1	n_2	n_3
P_1:	n_1	n_2	n_3	P'_1:	n_1	n_2	n_3
P_2:	n_1	n_2	n_3	P'_2:	n_1	n_2	n_3
P:	n_1	n_2	n_3	P':	n_1	n_2	n_3

6) (15 points) A doubly telecentric system is constructed out of two thin lenses in air. The spacing between the lenses is 250 mm, and the magnitude of the magnification |m| is 1/4.

a) Design and sketch the layout of the system. Provide the required focal lengths.

f_1 = ____________mm f_2 = ____________ mm

Continue to Part b…

b) A 12 mm high object is located 100 mm to the left of the first lens of this system. Determine the location and size of the image.

Cascaded imaging may not be used (you may not image through one lens and then use this image as an object for the other lens).

Raytrace methods may not be used for this problem.

The image is _______ mm to the _____ of L2. The image height is _______ mm.

7) (10 points) Prove the unlikely result that for a general optical system, the distance from the rear nodal point of the system to the rear focal point of the system $\left(\overline{N'F'}\right)$ is equal to minus the front focal length of the system $\left(-f_F\right)$.

Prove $\overline{N'F'} = -f_F$ for a general system.

Spare Raytrace Sheet:

Surface	0	1	2	3	4	5	6
f							
$-\phi$							
t							
y							
u							
y							
u							
y							
u							
y							
u							
y							
u							
y							
u							
y							
u							

Spare Raytrace Sheets:

Surface	0	1	2	3	4	5	6
C							
t							
n							
$-\phi$							
t/n							
y							
nu							
u							
y							
nu							
u							

Surface	0	1	2	3	4	5	6
f							
$-\phi$							
t							
y							
u							
y							
u							
y							
u							
y							
u							

OPTI-502 Equation Sheet

$$\mathrm{OPL} = nl$$

$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

$$\gamma = 2\alpha$$

$$d = t\left(\frac{n-1}{n}\right) = t - \tau$$

$$\phi = (n' - n)C$$

$$\frac{n'}{z'} = \frac{n}{z} + \phi$$

$$f_E = \frac{1}{\phi} = -\frac{f_F}{n} = \frac{f'_R}{n'}$$

$$m = \frac{z'/n'}{z/n} = \frac{\omega}{\omega'}$$

$$m = \frac{f_{F2}}{f'_{R1}} = -\frac{f_2}{f_1}$$

$$\bar{m} = \frac{n'}{n} m^2$$

$$\frac{\Delta z'/n'}{\Delta z/n} = m_1 m_2$$

$$m_N = \frac{n}{n'}$$

$$P'N' = PN = f_F + f'_R$$

$$\tau = \frac{t}{n} \qquad \omega = nu$$

$$\phi = \phi_1 + \phi_2 - \phi_1\phi_2\tau$$

$$\delta' = \frac{d'}{n'} = -\frac{\phi_1}{\phi}\tau \qquad \mathrm{BFD} = d' + f'_R$$

$$\delta = \frac{d}{n} = \frac{\phi_2}{\phi}\tau \qquad \mathrm{FFD} = d + f_F$$

$$\omega' = \omega - y\phi \qquad n'u' = nu - y\phi$$

$$\phi = -\frac{\omega'_k}{y_1}$$

$$y' = y + \omega'\tau' \qquad y' = y + u't'$$

$$f/\# \equiv \frac{f_E}{D_{EP}} \qquad NA \equiv n\left|\sin U\right| \approx n\left|u\right|$$

$$f/\#_W \equiv \frac{1}{2NA} \approx \frac{1}{2n\left|u\right|} \approx \left(1-m\right) f/\#$$

$$I = H = Ж = n\bar{u}y - nu\bar{y}$$

$$\bar{u} = \tan(\theta_{1/2})$$

$$MP = \frac{10\text{in}}{f} = \frac{250\text{mm}}{f}$$

$$MP = \frac{1}{m} \qquad MP = m_R MP_K$$

$$m_V = m_{OBJ} MP_{EYE}$$

$$L = \frac{M}{\pi} = \frac{\rho E}{\pi}$$

$$\Phi = LA\Omega \qquad \Omega \approx \frac{A}{d^2}$$

$$E' = \frac{\pi L_O}{4(f/\#_W)^2}$$

$$\text{Exposure} = H = E\,\Delta T$$

$$a \geq |y| + |\bar{y}| \qquad \text{Un}$$

$$a = |\bar{y}| \quad \text{and} \quad a \geq |y| \qquad \text{Half}$$

$$a \leq |\bar{y}| - |y| \quad \text{and} \quad a \geq |y| \qquad \text{Full}$$

$$DOF = \pm B' f/\#_W$$

$$L_H = -\frac{fD}{B'} \qquad L_{NEAR} = \frac{L_H}{2}$$

$$D = 2.44\lambda f/\#$$

$$D \approx f/\# \quad \text{in } \mu\text{m}$$

$$\text{Sag} \approx \frac{y^2}{2R}$$

$$\nu = \frac{n_d - 1}{n_F - n_C}$$

$$P = \frac{n_d - n_C}{n_F - n_C}$$

$$\delta = -(n-1)\alpha$$

$$\frac{\delta}{\Delta} = \nu \qquad \frac{\varepsilon}{\Delta} = P$$

$$\frac{\alpha_1}{\delta} = -\left(\frac{1}{\nu_1 - \nu_2}\right)\left(\frac{\nu_1}{n_{d1} - 1}\right)$$

$$\frac{\alpha_2}{\delta} = \left(\frac{1}{\nu_1 - \nu_2}\right)\left(\frac{\nu_2}{n_{d2} - 1}\right)$$

$$\frac{\varepsilon}{\delta} = \left(\frac{P_1 - P_2}{\nu_1 - \nu_2}\right)$$

$$n = \frac{\sin\left[(\alpha - \delta_{MIN})/2\right]}{\sin(\alpha/2)}$$

$$\theta_C = \sin^{-1}\left(\frac{n_S}{n_R}\right)$$

$$\frac{\delta\phi}{\phi} = \frac{\delta f}{f} = \frac{1}{\nu}$$

$$TA_{CH} = \frac{r_P}{\nu}$$

$$\frac{\phi_1}{\phi} = \frac{\nu_1}{\nu_1 - \nu_2} \qquad \frac{\phi_2}{\phi} = -\frac{\nu_2}{\nu_1 - \nu_2}$$

$$\frac{\delta\phi_{dC}}{\phi} = \frac{\delta f_{Cd}}{f} = \frac{\Delta P}{\Delta\nu}$$