Name________________________

Closed book; closed notes. Time limit: 2 hours.
An equation sheet is attached and can be removed. A spare raytrace sheet is also 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.
You must show your work and/or method of solution in order to receive credit or partial credit for your answer.
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.

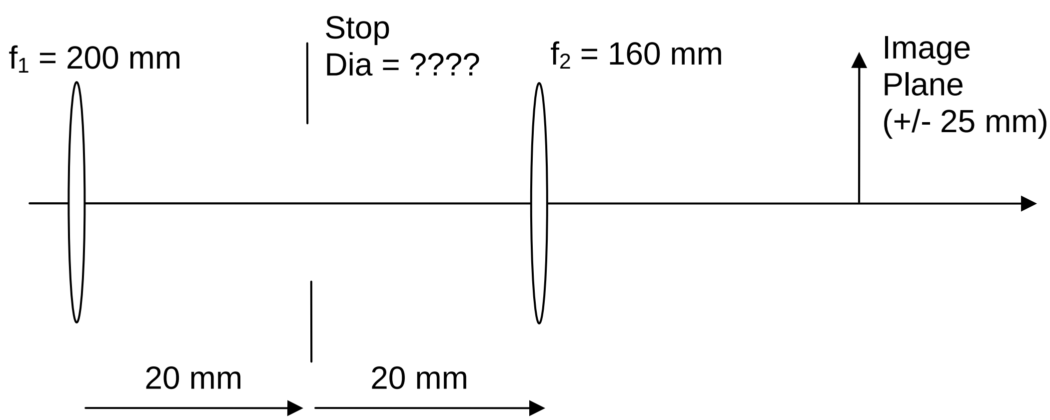
Distance Students: Please return the original exam only; do not scan/FAX/email an additional copy.

1) (10 points) Use two thin lenses in air to design a Petzval objective with a focal length of 100 mm and a back focal distance of 80 mm. The separation of the two lenses must be 40 mm. **Use Gaussian methods.**

f1 = __________ mm f2 = __________mm

2) (30 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 +/- 25 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. Gaussian imaging methods may not be used for any portion of this problem. The field of view must be determined from the chief ray.

Be sure to clearly label your rays on the raytrace form. Your answers must be entered below. Be sure to provide details on the pages that follow to indicate your method of solution (how did you get your answer: which ray was used, analysis of ray data, etc.).

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							

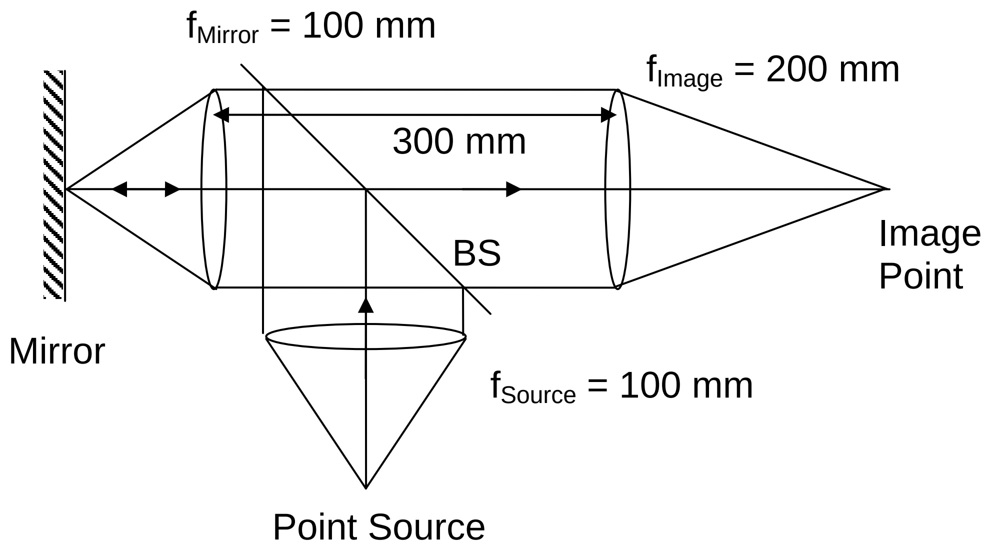
Continues…

Provide Method of Solution:

Continues…

Provide Method of Solution:

3) (30 points) Consider the following optical system:



A point source is imaged onto a mirror by two lenses ("Source Lens" and "Mirror Lens") and a beam splitter. The reflected light is then re-imaged by two lenses ("Mirror Lens" and "Image Lens") to a final image point as shown. The mirror is located at the focal point of the "Mirror Lens".

The separation between the "Mirror Lens" and the "Image Lens" is 300 mm forming an afocal system. The point source is located at the front focal point of the "Source Lens", and the combination of the "Source Lens" and the "Mirror Lens" also forms an afocal system.

The method of solution is not specified.

a) The mirror is translated 5 mm towards the "Mirror Lens" (to the right). How much does the image point move?

Image Shift = ______________ Direction ____________

b) Returning to the original configuration, the point source is translated down or away from the "Source Lens" by 2 mm. How much does the image point move?

Image Shift = ______________ Direction ____________

c) Returning to the original configuration, the point source is translated to the right by 2 mm (the distance to the "Source Lens" does not change). How much does the image point move?

Image Shift = ______________ Direction ____________

d) Returning to the original configuration, a block of glass 5 mm thick (n = 1.5) is inserted after (to the right of) the "Image Lens". How much does the image point move?

Image Shift = ______________ Direction ____________

e) Returning to the original configuration, a block of glass 5 mm thick (n = 1.5) is between the “Mirror Lens” and the mirror. How much does the image point move?

Image Shift = ______________ Direction ____________

f) Returning to the original configuration, the mirror is tilted by 2 degrees about its intersection point with the optical axis. How much does the image point move?

Image Shift = ______________ Direction ____________

g) The original system has been changed so that the separation between the "Mirror Lens" and the "Image Lens" is now 200 mm. Repeat part a) for this configuration: The mirror is translated 5 mm towards the "Mirror Lens" (to the right). How much does the image point move?

Image Shift = ______________ Direction ____________

4) (15 points) Design an object-space telecentric system consisting of a thin lens and a stop. The focal length of the lens is 100 mm, and the system operates at 1:1 conjugates. The system covers a field of view of ±10 mm, and it operates at a working f-number of 4 ($f/\#_W = 4$ or NA = 0.125). The system is unvignetted over this field of view.

Sketch the system and provide the required spacings, the diameter of the lens and the stop diameter.

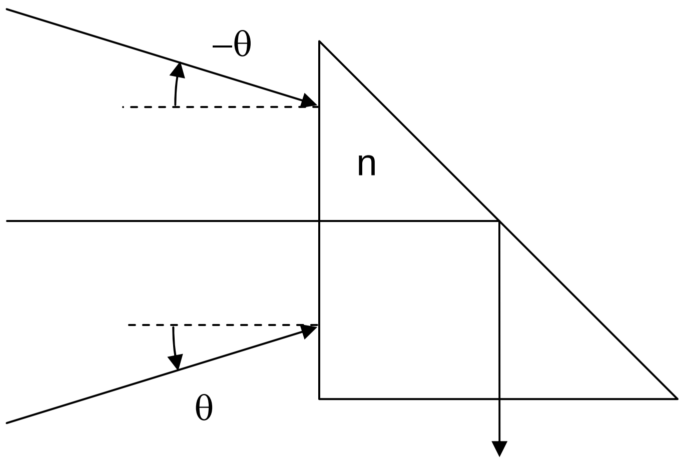
The method of solution is not specified.

Continues…

D_{Stop} = ___________mm D_{Lens} = ___________mm

Stop Location: _________mm to the ________ of the lens

5) (15 points) A right angle prism of index n is used to deviate a converging beam by 90 degrees. The fastest f/# or NA that the prism will support is limited by the loss of Total Internal Reflection at the hypotenuse of the prism. The prism is used in air.



a) Derive the expression for the fastest NA that is supported by the prism. At this limit, the entire converging beam undergoes TIR at the hypotenuse.

Continues…

b) Evaluate this expression for BaK4 glass (glass code = 569560). What is the f/# corresponding to this NA?

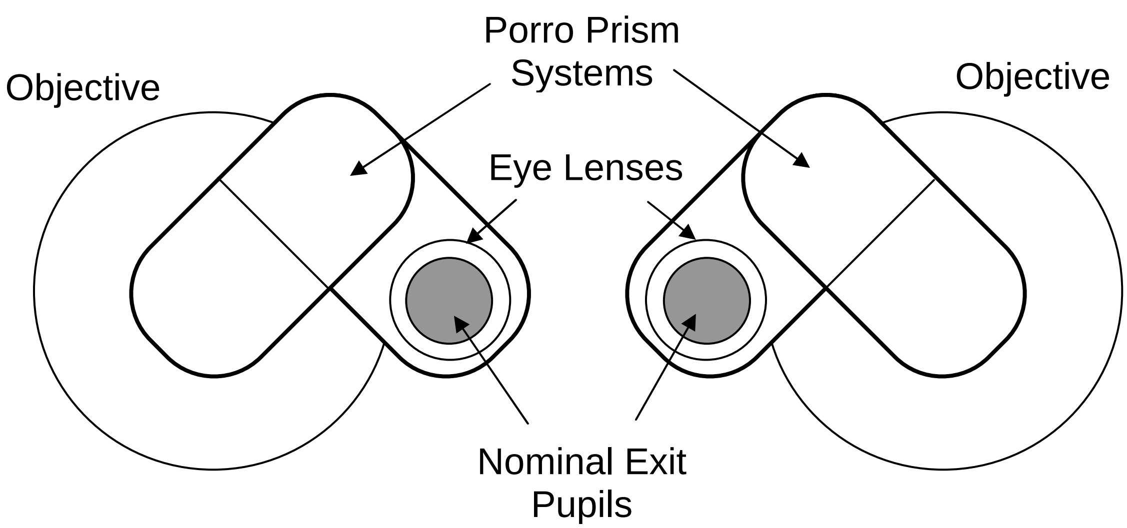
NA = ____________ f/#: ______________

Extra Credit (5 points)

The Porro Prism erecting system in a pair of binoculars can be thought of as four right angle prisms. If the objective lens used in the binoculars is faster than the TIR limit found in the preceding problem, what is the effect on the exit pupils?

Sketch the appearance of the exit pupils in this situation.

The orientation of the prisms is shown in this drawing of the binoculars as seen from the back. The prisms are oriented at ±45 degrees.



Sketches of Exit Pupils Showing the Effects of the Loss of TIR:

Spare raytrace forms:

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							

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							

OPTI-502 Equation Sheet

$$\mathrm{OPL} = nl$$

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

$$\gamma = 2\alpha$$

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

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

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

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

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

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

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

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

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

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

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

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

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

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

$$\omega' = \omega - y\phi$$

$$y' = y + \omega'\tau'$$

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

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

$$I = H = n\bar{u}y - nu\bar{y}$$

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

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

$$\mathrm{MP} = \frac{1}{m}$$

$$m_V = m_{OBJ}\mathrm{MP}_{EYE}$$

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

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

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

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

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

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

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

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

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

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

$D \approx f/\#$ in µm

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

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

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

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

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

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

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

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

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

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

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

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

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

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