Name________________________

Closed book; closed notes. Time limit: 120 minutes.
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.
As usual, only the magnitude of a magnification or magnifying power may be given.
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.
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 convention 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) (5 points) Design a 4X Galilean telescope (two thin lenses in air) with an overall length of 75 mm.

f_{OBJ} = ________mm f_{EYE} = ________mm

2) (15 points) Two thin lens achromatic doublets have focal lengths of 100 mm. The two achomats are constructed out of the following two pairs of glasses:

Acromat #1	N-BaK4	Glass Code:	569560	P = 0.303
	N-SF2	Glass Code:	648338	P = 0.292
Achromat #2	N-SK16	Glass Code:	620603	P = 0.305
	N-LaF21	Glass Code:	788475	P = 0.301

a) Determine the focal lengths of each of the elements in the two achromatic doublets.

b) Provide an explanation for how the combination of two different glasses in an achromatic doublet results in the correction of chromatic aberration.

c) Which of the two designs has the least excess power?

d) If the achromat is corrected for chromatic aberration, why does an achromat have secondary chromatic aberration?

e) Determine the secondary chromatic aberration each achromat.

Provide your answers and legible explanations in the spaces provided on the next page.

Continues…

a) Achromat #1 f1 = ________ mm f2 = _________ mm

Achromat #2 f1 = ________ mm f2 = _________ mm

b) Provide an explanation for how the combination of two different glasses in an achromatic doublet results in the correction of chromatic aberration.

c) Which of the two designs has the least excess power?

d) Why does an achromat have secondary chromatic aberration?

e) Achromat #1 δf_{Cd} = ______ mm Achromat #2 δf_{Cd} = ______ mm

3) (15 points) A 20X relayed Keplerian telescope is constructed out of three thin lenses in air. The relay lens of the telescope operates with a magnification of 2.0. The focal length of the objective lens is 200 mm, and the overall telescope length is 370 mm.

a) Determine the design of the telescope.

b) Assuming that the system stop is located at the objective lens, determine the eye relief of the telescope (distance from the eye lens to the XP).

NOTE: Only Gaussian imaging methods may be used for this problem. No raytrace analysis is permitted.

Continues…

f_{RELAY} = _______mm f_{EYE} = _______mm

Objective Lens-Relay Lens Separation = __________ mm

Relay Lens-Eye Lens Separation = __________ mm

Eye Relief = ________ mm

4) (10 points) For these two situations, determine the size and location of the entrance and exit pupils. A thin lens with a focal length 50 mm is used.

Note: Only Gaussian methods may be used for this problem. Raytraca analysis is not permitted.

a) A 10 mm diameter stop is located 25 mm to the right of the lens.

b) A 10 mm diameter stop is located 25 mm to the left of the lens.

5) (20 points) An object-space telecentric imaging system consists of a thin lens in air and a stop. The system has an object-to-image distance of 270 mm. A +/- 5 mm object is imaged onto a 20 mm wide detector. The resulting image fills the width of the detector. The system operates at an image space numerical aperture of NA = 0.05 and is unvignetted for this object size and location.

Provide the focal length and diameter of the lens, the stop diameter, and the required spacings.

Continues…

Focal Length = ___________mm

Lens Diameter = ___________mm

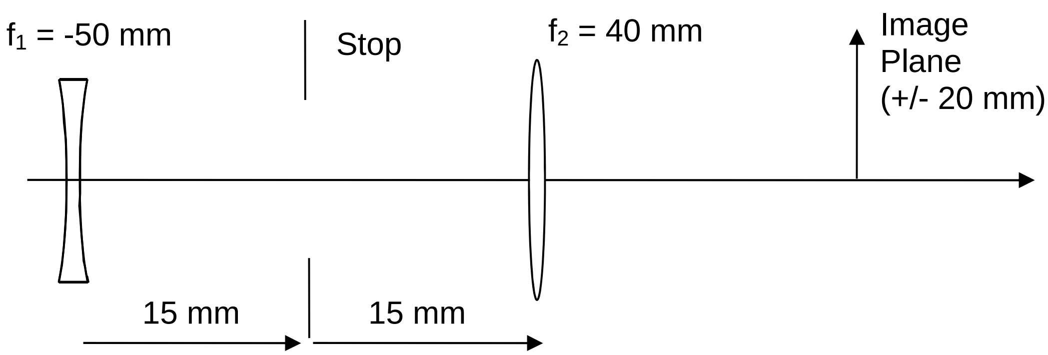
Stop Diameter = ___________mm

Stop Location: ___________mm to the __________ of the Lens

Image Location: ___________mm to the __________ of the Lens

6) (30 points) An f/4 reverse telephoto objective is comprised of two thin lenses in air. The system stop is located between the two lenses.

The system is now to be used with a finite conjugate object that is located 150 mm to the left of the first lens. The maximum image size is +/- 20 mm.



Determine the following:
- System focal length and back focal distance.
- Stop size; Entrance pupil and exit pupil locations and sizes.
- Image location.
- Object size corresponding to the image size.
- Required diameters for the two lenses for the system to be unvignetted over the specified maximum image size and conjugate location.

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 object size must be determined from the chief ray. Raytraces must be done on the raytrace form. Be sure to clearly label your rays on the raytrace form. Gaussian imaging methods may not be used for any portion of this problem.

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.)

System Focal Length = _________ mm Back Focal Distance = _________ mm

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

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

D_{STOP} = _______mm Object Size = ________ mm

Image Location: ________ mm to the _______ of the second lens.

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

Continues with a raytrace form on the next page…

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							

y							
u							

Continues…

Provide Method of Solution:

Continues…

Continues…

7) (5 points) The letter "A" is imaged by an aberration free thin lens (stop at the lens). A real image is produced. The diameter of the lens is 20 mm.

a) The top half of the lens is now blocked by an opaque card. What happens to the image?

b) An opaque dot is placed over the center of the lens. The dot has a diameter of 10 mm. What happens to the image?

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							
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

$$OPL = nl$$

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

$$\gamma = 2\alpha$$

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

$$a \le |\bar{y}| - |y| \quad \text{and} \quad a \ge |y| \qquad \text{Full}$$

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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