1) (5 points) Design a 4X Galilean telescope (two thin lenses in air) with an overall length of 75 mm.

\[ f_{\text{OBJ}} = \underline{\text{mm}} \quad f_{\text{EYE}} = \underline{\text{mm}} \]
2) (15 points) Two thin lens achromatic doublets have focal lengths of 100 mm. The two achromats 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.*
a) Achromat #1  \( f_1 = \text{______ mm} \)  \( f_2 = \text{______ mm} \)
Achromat #2  \( f_1 = \text{______ mm} \)  \( f_2 = \text{______ mm} \)

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  \( \delta f_{cd} = \text{______ mm} \)  Achromat #2  \( \delta f_{cd} = \text{______ mm} \)
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.
f_{RELAY} = _______ mm \quad 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

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Provide Method of Solution:

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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?
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OPTI-502 Equation Sheet

\[ \text{OPL} = nl \]
\[ n_1 \sin \theta_1 = n_2 \sin \theta_2 \]
\[ \gamma = 2\alpha \]
\[ d = t \left( \frac{n - 1}{n} \right) = t - \tau \]
\[ \phi = (n' - n)C \]
\[ \frac{n'}{z'} = \frac{n}{z} + \phi \]
\[ f_E = \frac{1}{\phi} = \frac{f_E'}{n} = \frac{f'_R}{n'} \]
\[ m = \frac{z'/n'}{z/n} = \frac{\omega}{\omega'} \]
\[ m = \frac{f_{F2}}{f_{R1}} = \frac{f_2}{f_1} \]
\[ \bar{m} = \frac{m'}{n} \]
\[ \frac{\Delta z'/n'}{\Delta z/n} = m_1m_2 \]
\[ m_N = \frac{n}{n'} \]
\[ P'N' = PN = f_E + f'_R \]
\[ \tau = \frac{t}{n} \quad \omega = nu \]
\[ \phi = \phi_1 + \phi_2 - \phi_1 \phi_2 \tau \]
\[ \delta' = \frac{d'}{n'} = -\frac{\phi_1}{\phi} \tau \quad \text{BFD} = d' + f'_R \]
\[ \delta = \frac{d}{n} = \frac{\phi_2}{\phi} \tau \quad \text{FFD} = d + f_F \]
\[ \omega' = \omega - y\phi \]
\[ y' = y + \omega' \tau' \]
\[ f/\# \equiv \frac{f_E}{D_{ep}} \quad \text{NA} \equiv n|\sin U| \approx n|u| \]
\[ f/\#_w \equiv \frac{1}{2NA} \approx \frac{1}{2n|u|} \approx (1 - m)f/\# \]
\[ I = H = n\bar{y} - nu\bar{y} \]
\[ \bar{u} = \tan(\theta_{1/2}) \]

\[ \text{MP} = \frac{10\text{in}}{f} = \frac{250\text{mm}}{f} \]
\[ \text{MP} = \frac{1}{m} \]
\[ m_v = m_{\text{OBJ}} \text{MP}_{\text{EYE}} \]
\[ L = \frac{M}{\pi} = \frac{\rho E}{\pi} \]

\[ \Phi = L \alpha \Omega \quad \Omega \approx \frac{A}{d^2} \]

\[ E' = \frac{\pi L_o}{4(f/\#_w)^2} \]

Exposure = \( E \Delta T \)

\[ a \geq |y| + |\bar{y}| \quad \text{Un} \]
\[ a = |\bar{y}| \quad \text{and} \quad a \geq |y| \quad \text{Half} \]
\[ a \leq |\bar{y}| - |y| \quad \text{and} \quad a \geq |y| \quad \text{Full} \]

DOF = \( \pm B' f/\#_w \)

\[ L_{H} = -\frac{fD}{B'} \quad L_{\text{NEAR}} = \frac{L_{H}}{2} \]

\[ D = 2.44 \lambda f/\# \]
\[ D \approx f/\# \quad \text{in \( \mu \text{m} \)} \]

\[ \text{Sag} \approx \frac{y^2}{2R} \]

\[ v = \frac{n_d - 1}{n_F - n_C} \]

\[ P = \frac{n_d - n_C}{n_F - n_C} \]

\[ \delta = -(n - 1)\alpha \]

\[ \frac{\delta}{\Delta} = \nu \quad \frac{\epsilon}{\Delta} = \rho \]

\[ \frac{\alpha_1}{\delta} = -\left(\frac{1}{v_1 - v_2}\right) \left(\frac{v_1}{n_d1 - 1}\right) \]
\[ \frac{\alpha_2}{\delta} = \left(\frac{1}{v_1 - v_2}\right) \left(\frac{v_2}{n_d2 - 1}\right) \]
\[ \frac{\varepsilon}{\delta} = \left(\frac{P_1 - P_2}{v_1 - v_2}\right) \]

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

\[ \theta_C = \sin^{-1}\left(\frac{n_s}{n_R}\right) \]

\[ \frac{\delta \phi}{\phi} = \frac{\delta f}{f} = \frac{1}{\nu} \]

\[ \text{TAC}_\text{CH} = \frac{r_p}{\nu} \]

\[ \frac{\phi_1}{\phi} = \frac{v_1}{v_1 - v_2} \quad \frac{\phi_2}{\phi} = -\frac{v_2}{v_1 - v_2} \]

\[ \frac{\delta \phi_{dc}}{\phi} = \frac{\delta f_{cd}}{f} = \frac{\Delta P}{\Delta \nu} \]