Name_______________________

Closed book; closed notes. The time limit is 2 hours.
Equation sheets are attached and can be removed.
Spare raytrace forms are also attached.
Use the back sides if required.
Do not use any pre-stored information or programs in your calculator.
Assume thin lenses in air if not specified.
If a method of solution is specified in the problem, it must be used.
You must show your work and/or method of solution in order to receive credit or partial credit for your answer.

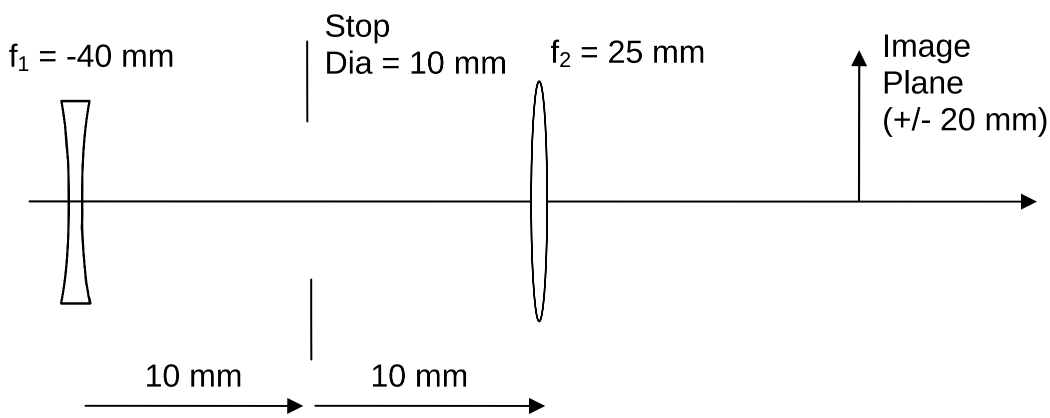
Distance Students: Please return the original exam only; do not scan/FAX/email an additional copy.

1) (10 points) Use two thin lenses in air to design a telephoto objective with a focal length of 400 mm and a back focal distance of 200 mm. The separation of the two lenses must be 75 mm.

f1 = _________ mm f2 = _________mm

2) (25 points) The following diagram shows the design of a reverse telephoto objective that is comprised of two thin lenses in air. The system stop is located between the two lenses.

The diameter of the stop is 10 mm.
The object is at infinity.
The maximum image size is +/- 20 mm.



Determine the following:
- Entrance pupil and exit pupil locations and sizes.
- System focal length.
- 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. 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

FOV = +/- _______ deg

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							

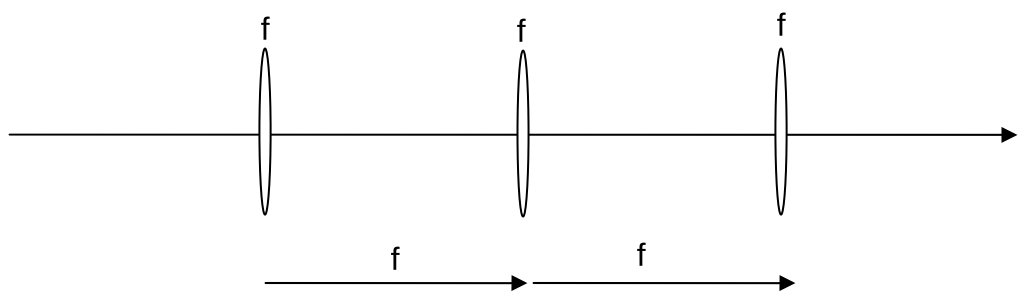
Continues…

Provide Method of Solution:

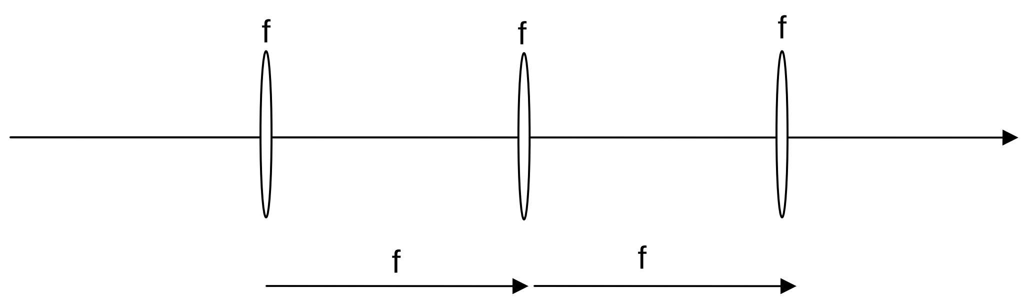
Continues…

Provide Method of Solution:

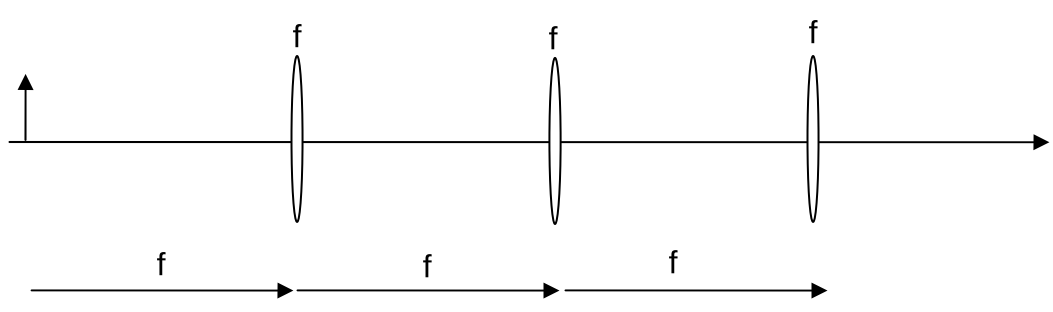
3) (20 points) Consider the following optical system comprised of three identical thin lenses of focal length f that are each separated by this same distance f:



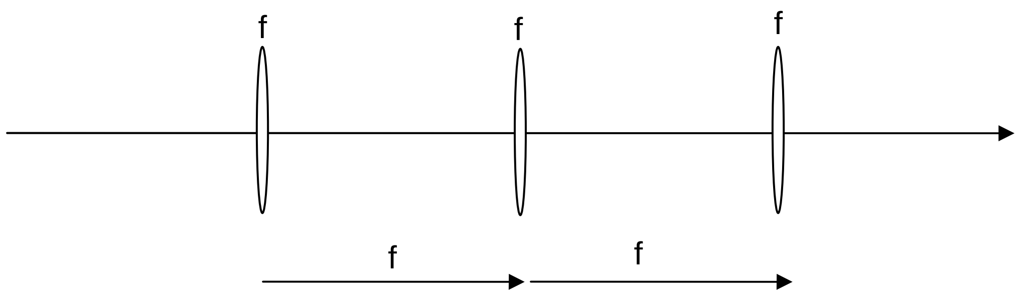
a) Determine the focal length of this system by sketching rays. No calculations are required or permitted.



b) An object is located at the front focal point of the first lens element. Determine the image location and size by sketching rays. No calculations are required or permitted.



c) Here equations are permitted. Explain the result of parts (a) and (b) by combining the second and third lenses into a reduced component that is used in conjunction with the first lens. Hint: consider the system to be analogous to a telescope with an objective lens and a compound eyepiece.

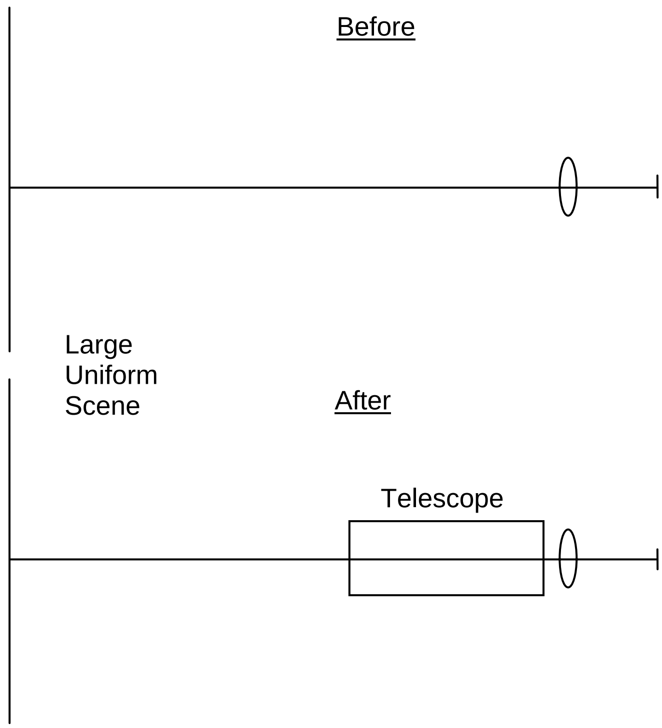


d) Where should the stop be located for the system to be telecentric in object space? Is there anything else you can then say about the telecentricity of the system?

4) (10 points) An imaging lens is used to image a large extended uniform object. The object greatly overfills the field of view defined by the detector used with the lens. Under these conditions, a certain irradiance E′ is incident on the detector.

A 5X telescope is now placed in front of the imaging lens. The telescope (aperture sizes, position, etc.) is designed so that the system stop of the combination of the telescope and the imaging lens remains at the imaging lens.

How does the irradiance on the detector change? You must explain how you obtained your answer.



5) (20 points) An object is located 75 mm to the left of the first element of a doubly-telecentric system. The conjugate image is located 10 mm to the right of the second element of the system. The image size is half the object size.

The system uses two thin lenses in air. Determine the system layout by providing the focal lengths of the two lenses, the required spacings and the stop position.

Continues…

f_1 = _________ mm f_2 = _________ mm t = _________ mm

Stop Location: ______________________________

6) (15 points) An 8X Keplerian telescope has a 240 mm focal length objective.

a) Determine the focal length of the eye lens and the overall length of the telescope.

f_2 = _________ mm L = _________ mm

b) If the stop of the telescope is at the objective, what is the eye relief?

ER = ________ mm

c) The objective lens has a diameter of 40 mm. What is the required eye lens diameter for the telescope to have an unvignetted field of view of +/- 2 degrees?

D_2 = _________ mm

Extra Credit (5 points)

A direct vision prism uses two opposing thin prisms to provide dispersion without deviation of the d light. For a desired dispersion Δ, the deviation δ is zero.

The properties of the two glasses are n_{d1}, ν_1 and n_{d2}, ν_2

Provide the equations for the two required prism angles α_1 and α_2 in terms of these glass values and the net dispersion Δ.

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

$$OPL = nl$$

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

$$\gamma = 2\alpha$$

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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