Name________________________

Closed book; closed notes. Equation sheets are attached and can be removed.
Use the back sides if required. The time limit is 2 hours.
Calculators are permitted, but do not use any pre-stored information or programs.
Note any assumptions you make in solving the problems.
Show your work. Present it in a neat and logical fashion.

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

1) (10 points) Name and briefly describe the three classifications of illumination systems.

2) (20 points) A camera objective is telecentric in object space and designed to image an object of size ±10 mm onto a detector of size ±5 mm. The working distance (from the object to the objective) is 125 mm. The system must be unvignetted over this field of view and have an image-space working F-number of f/4.

Model the objective as a single thin lens in air.

Determine the system layout including the position and diameter of the thin lens and the position and diameter of the system stop.

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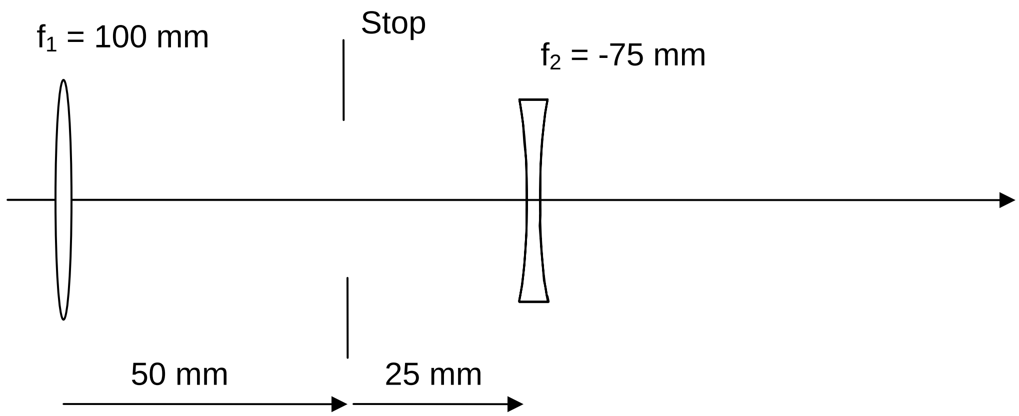
3) (20 points) The following thin-lens telephoto lens places the system stop between the two elements.



The system F-number is f/5. Use *Gaussian methods* to determine the Entrance Pupil location and diameter, the Exit Pupil location and diameter, and the Stop diameter.

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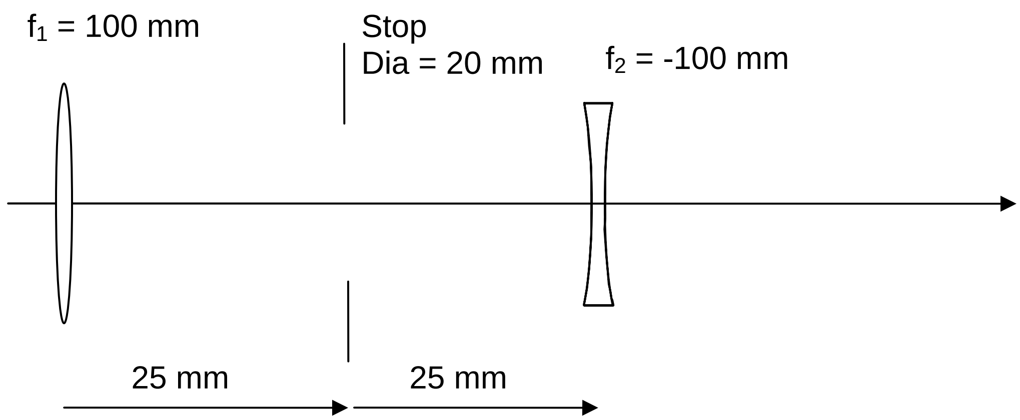
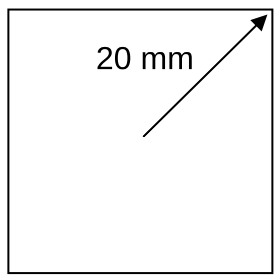
4) (20 points) A different thin-lens telephoto lens also places the system stop between the two elements. The object is at infinity.



This lens is used with a sensor that has a corner-to-corner dimension of 40 mm. What are the required element diameters for this system to be unvignetted over this field of view?



Use paraxial raytrace methods.

raytrace form on next page…

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

5) (15 points) A doubly telecentric system has a magnification of m = -3 and a length of 200 mm. The length is defined to be from the first lens element to the last lens element.

a) Show the system layout with focal lengths and spacings.

b) An object is located 40 mm to the left of the first element. Where is the image relative to the final element?

6) (15 points) A thin lens has a power ϕ in air. The glass has an index of refraction n_d with and Abbe number of ν_1. The lens is immersed into a fluid with the same index of refraction n_d. The fluid however has a different Abbe number ν_2.

When the lens is in the fluid, what is the longitudinal chromatic aberration of the power?

$$\delta\phi = \phi_F - \phi_C$$

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							

OPTI-502 Equation Sheet

$$OPL = nl$$

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

$$\gamma = 2\alpha$$

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

$$f/\# \equiv \frac{f_E}{D_{EP}} \qquad f/\#_W \approx (1-m)\, f/\#$$

$$NA = n\left|\sin U\right| \approx \frac{1}{2\, f/\#_W}$$

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

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

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

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

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

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

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

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

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

$a \geq |y| + |\bar{y}|$ — Un

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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