

Name _____

Closed book; closed notes. Equation sheets are attached and can be removed.

Spare raytrace forms are also attached.

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.

If a method of solution is specified in the problem, it must be used.

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 scan/FAX/email an additional copy.

1) (10 points) A 100 mm focal length thin lens (in air) is made out of glass KzFSN5. The glass code for this glass is 654396. What is the longitudinal chromatic aberration of this lens?

Longitudinal Chromatic Aberration = _____mm

2) (25 points) Design an object-space telecentric imaging system consisting of a thin lens and a stop. The system has an object-to-image distance of 450 mm, and it images a 20 mm diameter object onto a 10 mm square detector. The diameter of the image fills the width of the detector. The system operates at a working f-number of 4 ($f/\#_w = 4$ or $NA = 0.125$) and is unvignetted for this object.

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

3) (30 points) The telephoto ratio is defined as the ratio of the overall length of a lens system (as measured from the first element to the image plane) to the focal length of the system:

$$\text{Telephoto Ratio} = \frac{\text{System Length}}{\text{System Focal Length}}$$

The object is assumed to be distant. In other words, the telephoto ratio describes how much shorter an optical system is when compared to an equivalent single thin lens system.

An $f/5.6$ lens system is constructed with two thin lenses in air.

The system has a telephoto ratio of 0.75.

The system has a focal length of 200 mm.

The system provides a back focal distance of 70 mm.

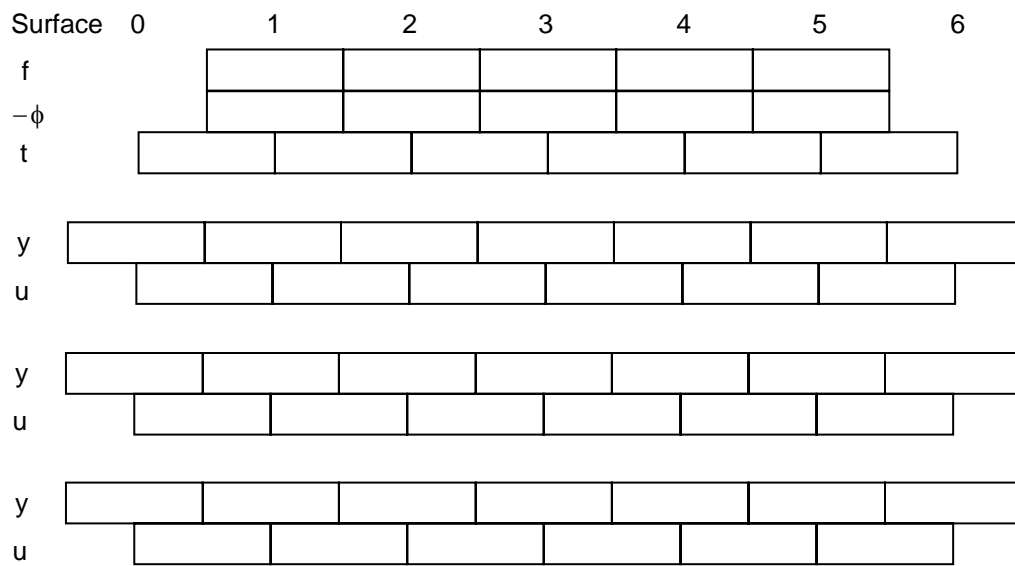
The system stop is located halfway between the two thin lenses.

The object is at infinity.

The lens is unvignetted when used with a detector that has a diameter of 30 mm.

Determine the focal lengths and diameters of the two thin lenses, the stop diameter, and the element spacings. Also determine the angular Field of View in Object Space.

Continues...



Continues...

Lens 1: Focal Length = _____mm

Diameter = _____mm

Lens 2: Focal Length = _____mm

Diameter = _____mm

Separation between Lens 1 and Lens 2 = _____mm

Stop Diameter = _____mm

Angular FOV = +/- _____ degrees

4) (15 points) As is common, a fixed focus camera has a hyperfocal distance of 8.0 feet, providing in focus images for objects from 4 feet to infinity. The camera is used in air.

To use this same camera underwater, a water-proof box is provided with a thin, flat window. The camera lens is in close proximity to the window. No adjustments to the camera are made.

When the camera is used underwater, what is the hyperfocal distance and range of in-focus objects? The index of refraction of water is 1.33.

Hyperfocal Distance = _____ feet

Range of In-Focus Objects: _____ feet to _____ feet

5) (20 points) An earth-resource satellite will contain an refractive imaging system that images a 100 kilometer wide swath of the earth onto a 100 mm wide detector array. The satellite orbits at a height of 700 kilometers.

The lens system is to be tested on earth and in air. How much should the detector array be shifted (refocused) prior to launch to compensate for the fact that the optical system will operate in vacuum? Which direction is the detector shifted?

Model the optical system as a thin lens with an index of refraction of 1.5000 relative to air. The index of refraction of air is 1.0003.

Continues...

Detector shift = _____mm

Shift Direction: _____

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

$$\text{OPL} = n l$$

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

$$\gamma = 2\alpha$$

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

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

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

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

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

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

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

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

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

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

$$\tau = \frac{t}{n} \quad \omega = n u$$

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

$$\text{DOF} = \pm B' f / \#_w$$

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

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

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

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

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

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

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

$$\frac{\delta}{\Delta} = v \quad \frac{\varepsilon}{\Delta} = P$$

$$\frac{\alpha_1}{\delta} = -\left(\frac{1}{v_1 - v_2}\right)\left(\frac{v_1}{n_{d1} - 1}\right)$$

$$\frac{\alpha_2}{\delta} = \left(\frac{1}{v_1 - v_2}\right)\left(\frac{v_2}{n_{d2} - 1}\right)$$

$$\frac{\varepsilon}{\delta} = \left(\frac{P_1 - P_2}{v_1 - v_2}\right)$$

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

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

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

$$\text{TA}_{\text{CH}} = \frac{r_P}{v}$$

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

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