Name________________________

Closed book; closed notes. Time limit: 120 minutes.
An equation sheet is attached and can be removed. Spare raytrace sheets are attached.
Use the back sides if required.
Assume thin lenses in air if not specified.
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. No credit if it can't be read/followed.
Use a ruler or straight edge!
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 conventions and reference definitions 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) A 100 mm focal length thin lens (in air) in made out of glass N-KzFS5. The glass code for this glass is 654397. What is the longitudinal chromatic aberration of this lens?

Longitudinal Chromatic Aberration = δf = _________mm

2) (10 points) For a thin lens in air with a focal length f, it is well known that the minimum object-to-image distance L is 4f. This result assumes a real object and a real image. Derive this result.

$$\frac{d}{dx}(uv) = u\frac{dv}{dx} + v\frac{du}{dx}$$

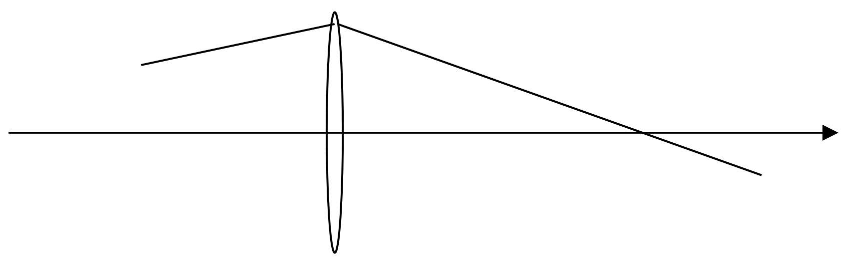
$$\frac{d}{dx}e^u = e^u\frac{du}{dx}$$

$$\frac{d}{dx}\left(\frac{u}{v}\right) = \frac{1}{v}\frac{du}{dx} - \frac{u}{v^2}\frac{dv}{dx}$$

$$\frac{d}{dx}\left(u^n\right) = nu^{n-1}\frac{du}{dx}$$

$$\frac{d}{dx}\sin u = \cos u\frac{du}{dx}$$

3) (10 points) The figure shows a ray path through a thin lens. Draw a single line on the figure to locate the rear focal plane of the lens. No calculations are allowed or required. Explain your result.



4) (15 points) Design a doubly telecentric system using two thin lenses (in air). The overall object-to-image distance is required to be 200 mm, and the image size is one third the object size. The object and image must both be real. The image-space working F-number is f/5.

Determine the focal lengths, lens separation, object and image positions, stop location and stop size. The lens element diameters are not required. Sketch the system.

f_1 = ______ mm f_2 = ______ mm Separation = _______ mm D_{STOP} = _______ mm

5) (15 points) Use Gaussian reduction to determine the focal length and the back focal distance of the following three surface optical system:

$n = n_0 = 1.33$
$R_1 = 25.0$
$n_1 = 1.50$
$t_1 = 5.0$
$R_2 = -40.0$
$n_2 = 1.60$
$t_2 = 5.0$
$R_3 = -60.0$
$n' = n_3 = 1.33$

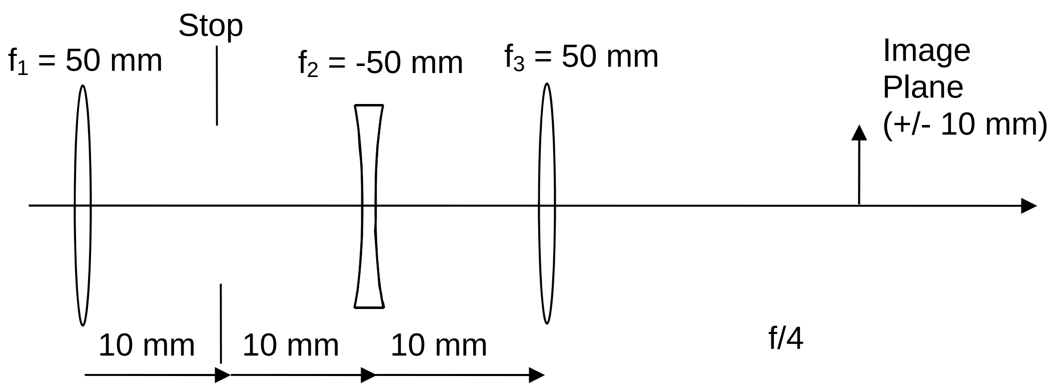
NOTE: Use Gaussian Reduction and Gaussian Imaging for this problem. **Cascaded imaging may not be used (you may not image through one surface and then use this image as an object for the next surface). Solutions obtained using raytrace methods will receive zero credit.**

Continues…

f = ________ mm BFD = _________ mm

6) (25 points) The following diagram shows the design of an objective that is comprised of three thin lenses in air. The stop is located between the first two lenses as shown.

The system operates at f/4. The object is at infinity.
The maximum image size is +/- 10 mm.



Determine the following:
- System focal length.
- Back focal distance
- Entrance pupil and exit pupil locations and sizes.
- Stop Diameter.
- 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. All answers must be determined directly from the rays you trace; for example, the image size must be determined from a separate raytrace. Raytraces must be done on the raytrace form. Be sure to clearly label your rays on the raytrace form. A method of solution explaining your procedure and calculations must be provided. Calculations may NOT be done in the margins of the raytrace sheet. Gaussian imaging methods may not be used for any portion of this problem.

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

Exit Pupil: _________ mm to the _______ of the third lens. D_{XP} = _________ mm

System Focal Length = __________ mm Back Focal Distance = __________mm

Stop Diameter = __________ mm FOV = +/- _______ deg in object space

Lens 1 Diameter = __________ mm Lens 2 Diameter = ___________ mm

Lens 3 Diameter = ___________ mm

Surface	0	1	2	3	4	5	6	7
f								
$-\phi$								
t								
y								
u								
y								
u								
y								
u								
y								
u								
y								
u								
y								
u								
y								
u								

Continues…

Provide Method of Solution:

Continues…

7) (20 points) A microscope consists of an objective lens and an eyepiece. The Optical Tube Length for this microscope is 160 mm. The OTL is the distance from the rear focal point of the objective and the intermediate image formed by the objective.

a) The objective is labeled as 10X. Determine the focal length of the objective lens and the working distance of the objective in this configuration. The working distance is the distance from the object to to objective lens. Assume the objective is a thin lens in air.

f_{OBJ} = ________ mm WD = __________ mm *Problem Continues…*

b) When coupled with a 10X eyepiece, this microscope will have a visual magnification of 100X ($|m_V| = 100$).

A microscope is often described as a compound magnifier. Prove that this is true by using Gaussian Reduction to turn this microscope into a magnifier – a single optical system with a focal length. Determine this focal length.

Show that the reduced magnifier functions the same as the microscope – that it is has the same magnification and working distance.

Assume the eyepiece is a thin lens in air and the the image is presented to a relaxed eye.

f = ________mm MP = ________ WD = _______mm

Spare Raytrace Sheet:

Surface	0	1	2	3	4	5	6	7
f								
$-\phi$								
t								

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

$$OPL = nl$$

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

$$\gamma = 2\alpha$$

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

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

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

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

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

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

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

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

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

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

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

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

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

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

$$\omega' = \omega - y\phi \qquad n'u' = nu - y\phi$$

$$\phi = -\frac{\omega'_k}{y_1}$$

$$y' = y + \omega'\tau' \qquad y' = y + u't'$$

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

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

$$I = H = Ж = n\bar{u}y - nu\bar{y}$$

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

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

$$MP = \frac{1}{m} \qquad MP = m_R MP_K$$

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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