1) (10 points) An 8 m tall building is imaged with a camera using a 90 mm focal length lens. The camera is 45 m away from the building. Approximately how large is the image of the building?

Image Size = __________ 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 assumes a real object and a real image. Derive this result.

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

\[
\frac{d}{dx} e^u = e^u \frac{du}{dx}
\]

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

\[
\frac{d}{dx} (u^n) = nu^{n-1} \frac{du}{dx}
\]

\[
\frac{d}{dx} \sin u = \cos u \frac{du}{dx}
\]
3) (10 points) As shown below, a concave refracting surface separates an index of refraction of 1.8 from an index of 1.5. The magnitude of the radius of curvature of the surface is 25 mm. A 10 mm high object is 200 mm to the left of the surface.

Where is the image and how big is it?

**NOTE**: Only Gaussian methods may be used for this problem.

![Diagram](image)

Image size is _______ mm and it is located _______ mm to the ________ of the surface.
4) (20 points) A 5 mm high object is 250 mm to the left of the front vertex of a thick lens in air. The lens specifications are:

\[ \begin{align*}
R_1 &= 75 \text{ mm} \\
R_2 &= -50 \text{ mm} \\
t &= 12 \text{ mm} \\
n &= 1.55
\end{align*} \]

Determine the focal length of the lens.
Determine the image size and the image location relative to the rear vertex of the lens.

**NOTE:** Only Gaussian methods may be used for this problem.
Focal length = _______ mm

Image size = _______ mm  Located _______ mm to the ______ of the rear vertex.
5) (20 points) A 20 mm diameter stop is located between two thin lenses in air as shown.

Determine the system focal length and the system back focal distance. Determine the entrance pupil and exit pupil locations and diameters. The entrance pupil is to be located relative to the first lens, and the exit pupil is to be located relative to the second lens.

**NOTE:** Only Gaussian methods may be used for this problem.
Focal length = ________ mm  

Back Focal Distance = ________ mm

EP:  $D_{EP} = ________$ mm;  
Located ________ mm to the ________ of the first lens.

XP:  $D_{XP} = ________$ mm;  
Located ________ mm to the ________ of the second lens.
6) (30 points) The following diagram shows the design of an objective that is comprised of three thin lenses in air.

The system operates at f/3. The object is at infinity.

![Diagram of three thin lenses in air with f/3 notation and maximum image size of +/- 15 mm.]

The maximum image size is +/- 15 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).

**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 field of view must be determined from the chief ray. 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 third lens. \( D_{XP} = \) ________ mm

**Stop Diameter** = ________ mm

**System Focal Length** = ________ mm  \( \text{Back Focal Distance} = \) ________ mm

**FOV** = +/- ________ deg in object space
Continues…
Provide Method of Solution:

Continues...
### Spare raytrace sheet

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OPTI-502 Equation Sheet
Midterm

\[ OPL = nl \]
\[ n_1 \sin \theta_1 = n_2 \sin \theta_2 \]
\[ \gamma = 2\alpha \]
\[ d = t \left( \frac{n - 1}{n} \right) = t - \tau \]
\[ \phi = (n' - n)C \]
\[ \frac{n'}{z'} = \frac{n}{z} + \phi \]
\[ f_E = \frac{1}{\phi} = \frac{-f_F}{n} = \frac{f'_R}{n'} \]
\[ m = \frac{z'/n'}{z/n} = \frac{\omega}{\omega'} \]
\[ m = \frac{f_{F_2}}{f'_{R_1}} = \frac{-f_2}{f_1} \]
\[ \bar{m} = \frac{n'}{n} \]
\[ \frac{\Delta z'/n'}{\Delta z/n} = m_1m_2 \]
\[ m_N = \frac{n}{n'} \]
\[ P'N' = PN = f_F + f'_R \]
\[ \tau = \frac{t}{n} \quad \omega = nu \]
\[ \phi = \phi_1 + \phi_2 - \phi_1\phi_2\tau \]
\[ \delta' = \frac{d'}{n'} = -\frac{\phi_1}{\phi} \quad \text{BFD} = d' + f'_R \]
\[ \bar{\delta} = \frac{d}{n} = \frac{\phi_2}{\phi} \quad \text{FFD} = d + f_F \]
\[ \omega' = \omega - y\phi \]
\[ y' = y + \omega'\tau' \]
\[ f/# \equiv \frac{f_E}{D_{EP}} \quad \text{NA} \equiv n|\sin U| \approx n|u| \]
\[ f/#_W = \frac{1}{2\text{NA}} \approx \frac{1}{2n|u|} \approx (1 - m)f/# \]
\[ I = H = n\bar{u} - n\bar{u} \]
\[ \bar{u} = \tan(\theta_{1/2}) \]