Homework is due in class. Do all problems and show your work. Credit is not given for answers only. You are welcome to work together, but be sure your homework is your work.

1. Suppose we measure an unknown thick lens system with the reciprocal magnification technique. We measure a magnification $m_1 = -1.5$ when the lens is in the first position and the object is sharply focused on the image plane. We then shift the lens 30 mm to again bring the object into focus at the second position. Answer the following questions:
   a) What is the magnification $m_2$ when the lens is in the second position?
   b) What is the effective focal length of the lens?
   c) What are the object and image distances $z$ and $z'$ when the object is in the first position?
   d) Where are the nodal points located?
   e) If the separation of the front and rear principal planes is 10 mm, what is the distance between the object and image planes?

2. A reverse telephoto zoom lens consists of two thin lenses with powers $\phi_1 = -0.005 \text{ mm}^{-1}$ and $\phi_2 = 0.025 \text{ mm}^{-1}$, respectively. The lenses are spaced by a distance $t$ and the image plane is located at the rear focal point a distance $BFD$ to the right of the second lens. Using your Gaussian reduction knowledge, do the following:
   a) Show that the total power of the zoom lens is given by $\phi = \frac{\phi_1}{1 - \phi_2 \cdot BFD}$.
   b) Show that the separation between the two lenses is given by $t = \frac{\phi_1 + \phi_2 - \phi}{\phi_1 \phi_2}$.
   c) Fill in the columns of the table below

<table>
<thead>
<tr>
<th>$BFD$</th>
<th>$\phi$</th>
<th>$t$</th>
<th>$z_1 = -t - BFD$</th>
<th>$z_2 = -BFD$</th>
<th>$f_R'$</th>
</tr>
</thead>
<tbody>
<tr>
<td>50 mm</td>
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<td>49 mm</td>
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<td>46 mm</td>
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</tbody>
</table>

d) The values $z_1 = -t - BFD$ and $z_2 = -BFD$ are the positions of the two lenses with respect to the image plane. Plot these positions versus $f_R'$. 
Use *ynu raytracing and not Gaussian reduction* to solve the problems below. Credit will not be given for Gaussian reduction. Obviously, your answers should be identical between the two techniques, so you can use Gaussian reduction to check your answers. Turn in a copy of your spreadsheets and clearly show how you calculated the various values from the elements of the spreadsheet.

3. The parameters of a Hastings triplet are shown in the figure below.

![Hastings Triplet Diagram](image)

(a) Use *ynu raytracing to find the location of all six cardinal points, as well as the BFD and FFD Include your raytracing worksheets and show all work.

(b) Answer the following:

- What is the front focal length of the system?
- What is the rear focal length of the system?
- What is the total power of the system?
- For an object located 25 mm to the left of the front principal plane, where is the image formed and what is its magnification?

4. A Gregorian telescope has two reflective mirrors. The first mirror has a radius of curvature of \( R_1 = -500 \text{ mm} \). The second mirror lies to the left of the first mirror such that \( t'_1 = -150 \text{ mm} \). The radius of curvature of the second mirror is \( R_2 = 125 \text{ mm} \).

(a) Sketch the telescope and label the vertices, V1 and V2.

(b) Use *ynu raytracing to trace a ray with \( y_1 = 50 \text{ mm} \) and \( u_1 = 0 \). Where is the rear principal plane located with respect to the vertex V2?

(c) Where is the rear focal point located with respect to vertex V2?
5. A system consists of two thin lenses separated by a distance of 70 mm. The focal length of the first lens is 3.75 mm and the focal length of the second lens is 10 mm. An object is located 4 mm to the left of the first lens. The object has a height of 0.5 mm. Using ynu raytracing, trace the following to rays through the system.

(a) The a-ray has a height $y_{a0} = 0$ at the object and a slope $u_{a1} = 0.25$ incident on the first surface.

(b) The b-ray has a height $y_{b0} = 0.5$ mm at the object and a slope $u_{b1} = -0.125$ incident on the first surface.

(c) Calculate the optical invariant at each surface to double check you work.

(d) What is the slope $u'_{a2}$ of a-ray leaving the second lens?

(e) Where does the b-ray cross the optical axis after the second lens?

(f) What is the ratio $\frac{u'_{b2}}{u_{b1}}$?

(g) Sketch the system and the locations of the two rays as they propagate through the system.