If signs ever seem off, download the PDF of the solutions—D2L has been compressing images and equations in weird and very frustrating ways.

## 1. Stop and Lens Vignetting

A thin lens, $f = 80mm$, is used to image an object with a magnification of $m = -\frac{1}{2}$. The lens diameter is $D_{lens} = 25mm$ and the stop, $D_{stop} = 20mm$, is located $40mm$ in front of the lens. You may use any methods for this question.

a. When unvignetted at the lens, determine the unvignetted object diameter (FOV) in mm.

b. Repeat the above for the fully vignetted condition.

$$m = \frac{z'}{z} = -\frac{1}{2}$$

$$\frac{1}{z'} = \frac{1}{z} + \frac{1}{f} \rightarrow 1 = \frac{z'}{z} + \frac{z'}{f} \rightarrow z' = f \cdot \frac{3}{2} = 120mm$$

$$z = -2z' = -240mm$$

At the stop

$$y_{stop} = 10mm, \qquad u_{stop} = \frac{10mm}{(240 - 40)mm} = 0.05$$

$$\overline{y_{stop}} = 0, \qquad \bar{u} = -\frac{\overline{y_{obj}}}{200mm}$$

Transfer to the lens

$$t = 40mm$$

$$y' = y + ut$$

$$y_{lens} = 10mm + 0.05 \cdot 40mm = 12mm$$

$$\overline{y_{lens}} = 0 - \left(\frac{\overline{y_{obJ}}}{200mm}\right) \cdot 40mm = -0.2\overline{y_{obJ}}$$

For unvignetted at the lens

$$\frac{D_{lens}}{2} = \overline{|y_{lens}|} + |y_{lens}|$$

$$12.5mm = 0.2\overline{y_{obJ}} + 12mm$$

$$0.2\overline{y_{obJ}} = 0.5mm$$

$$\overline{y_{obJ}} = 2.5mm, \qquad \bar{u} = -0.0125$$

Unvignetted object diameter FOV $5mm$

For fully vignetted at the lens

$$\frac{D_{lens}}{2} = \overline{|y_{lens}|} - |y_{lens}|$$

$$12.5mm = 0.2\overline{y_{obJ}} - 12mm$$

$$0.2\overline{y_{obJ}} = 24.5mm$$

$$\overline{y_{obJ}} = 122.5mm, \qquad \bar{u} = -0.6125$$

Fully vignetted object diameter FOV $245mm$

You could also determine the above by doing a paraxial raytrace with an unscaled chief ray. You should then scale the chief ray to fulfil the unvignetted and fully vignetted conditions, resulting in the same solution.

| | Object | Stop | Lens | Image |
|---|---|---|---|---|
| R or f | | | 80 | |
| t | 200 | 40 | 120 | |
| n | 1 | 1 | 1 | |
| `-ϕ | | | -0.0125 | |
| t/n | | | | |
| | **Scaled Marginal Ray** | | | |
| y | 0 | 10 | 12 | 0 |
| nu | 0.05 | 0.05 | -0.1 | |
| u | 0.05 | 0.05 | -0.1 | |
| | **Unscaled Chief Ray** | | | |
| y | -20 | 0 | 4 | 10 |
| nu | 0.1 | 0.1 | 0.05 | |
| u | 0.1 | 0.1 | 0.05 | |
| | **Scaled Chief Ray (UNVIGNETTED AT THE LENS)** | | | |
| y | -2.5 | 0 | 0.5 | 1.25 |
| nu | 0.0125 | 0.0125 | 0.00625 | |
| u | 0.0125 | 0.0125 | 0.00625 | |
| | **Scaled Chief Ray (FULLY VIGNETTED AT THE LENS)** | | | |
| y | -122.5 | 0 | 24.5 | 61.25 |
| nu | 0.6125 | 0.6125 | 0.30625 | |
| u | 0.6125 | 0.6125 | 0.30625 | |

## 2. Air-Spaced Triplet

An air-spaced triplet objective is comprised of three thin lenses in air. The first lens, $f_1 = 100mm$, is located $t_{12} = 25mm$ from the second lens. The second lens, $f_2 = -50mm$, is located $t_{2S} = 25mm$ from the stop. The stop, $D_{stop} = 20mm$, is located $t_{S3} = 50mm$ from the final lens, $f_3 = 100mm$. Draw a diagram of the set up from the information given.

a. For an object located at infinity, determine the following properties of the system using paraxial raytrace methods.

   i. Entrance pupil location and size

$71.43mm$ to the right of lens 1, with a diameter of $D_{EP} = 11.43mm$

   ii. Exit pupil location and size

$100.00mm$ to the left of lens 3, with a diameter of $D_{XP} = 12.86mm$

   iii. System Focal length

$f_E = 160mm$

   iv. Back focal distance

$BFD = 180mm$

b. The maximum image height of the system is $h' = 50mm$. Determine the following.

   i. FOV for the image space

Image Space: $FOV = +/-10.12^o$ (also can be written as $FOV = 50mm$ image diameter)

ii. Required lens diameters for the system to be unvignetted

Lens 1: $D_1 = 2(11.43mm + 22.32mm) = 67.50mm$

Lens 2: $D_2 = 2(8.57mm + 8.93mm) = 35.00mm$

Lens 3: $D_3 = 2(12.86mm + 17.86mm) = 61.43mm$

iii. FOV for the object space

Object Space: $FOV = +/-17.35^o$

| Object | EP | Lens 1 | Lens 2 | Stop | Lens 3 | XP | Image |
|---|---|---|---|---|---|---|---|
| | | 100 | -50 | | 100 | | |
| | -71.42857143 | 25 | 25 | 50 | -100 | 280 | |
| 1 | 1 | 1 | 1 | 1 | 1 | 1 | |
| | | -0.01 | 0.02 | | -0.01 | | |
| | | 25 | 25 | 50 | | | |
| **Unscaled Marginal Ray** | | | | | | | |
| 1 | 1 | 1 | 0.75 | 0.875 | 1.125 | 1.75 | |
| 0 | 0 | -0.01 | 0.005 | 0.005 | -0.00625 | | |
| 0 | 0 | -0.01 | 0.005 | 0.005 | -0.00625 | | |
| **Scaled Marginal Ray** | | | | | | | |
| 11.42857143 | 11.42857143 | 11.42857143 | 8.571428571 | 10 | 12.85714286 | 20 | 0 |
| 0 | 0 | -0.114285714 | 0.057142857 | 0.057142857 | -0.071428571 | -0.071428571 | |
| 0 | 0 | -0.114285714 | 0.057142857 | 0.057142857 | -0.071428571 | -0.071428571 | |
| **Unscaled Chief Ray** | | | | | | | |
| | 0 | -6.25 | -2.5 | 0 | 5 | 0 | 14 |
| | 0.0875 | 0.15 | 0.1 | 0.1 | 0.05 | 0.05 | |
| | 0.0875 | 0.15 | 0.1 | 0.1 | 0.05 | 0.05 | |
| **Scaled Chief Ray** | | | | | | | |
| | 0 | -22.32142857 | -8.928571429 | 0 | 17.85714286 | 0 | 50 |
| | 0.3125 | 0.535714286 | 0.357142857 | 0.357142857 | 0.178571429 | 0.178571429 | |
| | 0.3125 | 0.535714286 | 0.357142857 | 0.357142857 | 0.178571429 | 0.178571429 | |

If you believe the signs are wrong on screenshots of excel, download the solutions—D2L compresses the image in a way that keeps cutting out negative signs?? It's weird. Excel spreadsheet solutions can also be found on D2L.