Note the following key equations for paraxial YNU raytraces.

$$\omega = nu \qquad \varphi = (n' - n)C = (n' - n)/R = 1/f_E \qquad \tau' = t'/n'$$

YNU Raytrace (direction of object space to image space)

Refraction or Reflection $\quad n'u' = nu - y\varphi \qquad \omega' = \omega - y\varphi$

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

Reverse YNU Raytrace (direction of image space to object space)

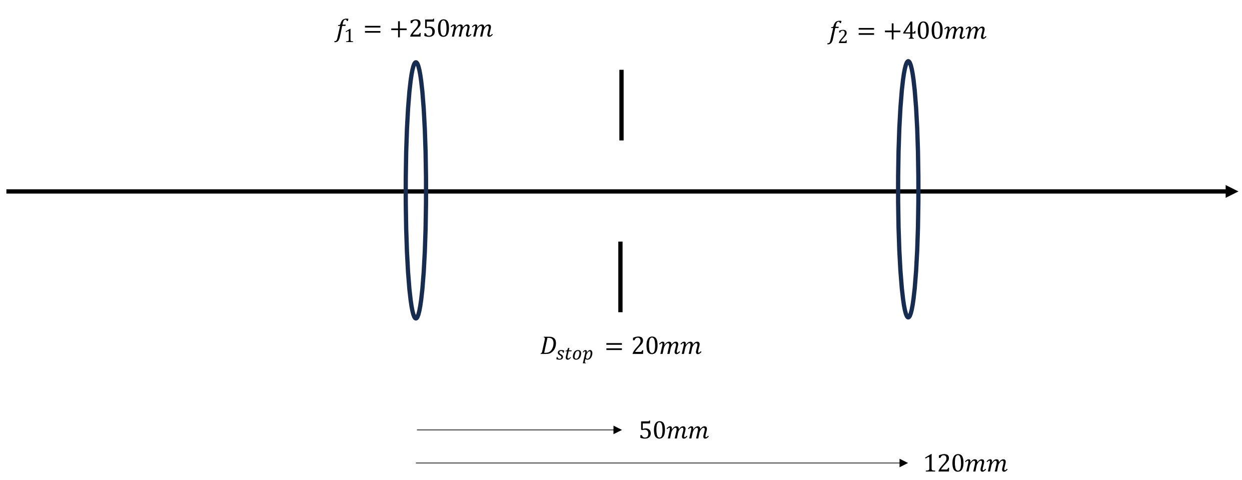
Refraction or Reflection $\quad nu = n'u' + y\varphi \qquad \omega = \omega' + y\varphi$

Transfer $\quad y = y' - u't' \qquad y = y' - \omega'\tau'$

Note, ` at the beginning of cells in excel is used because you cannot begin a text cell with a - alone. It has no hidden meaning.

1. Pupil Location

First using (a) paraxial raytrace methods, then using (b) Gaussian methods, determine the location and size of the entrance and exit pupils for the following system in air.



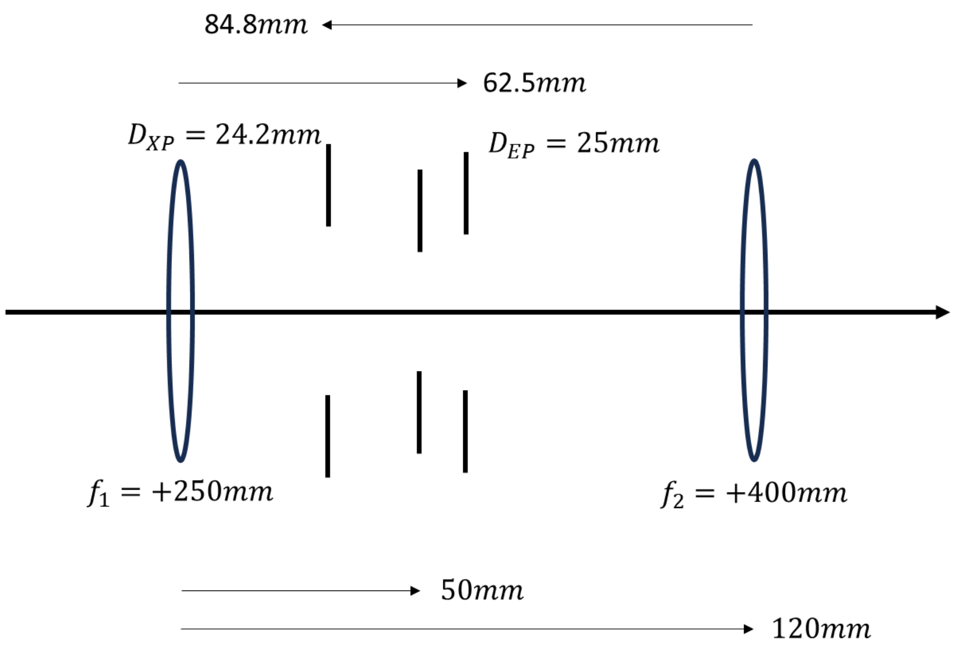
f			250				400		
t		EP-L1		50		70		L2-XP	
n		1		1		1		1	
`-ϕ			-0.004		0		-0.0025		
t/n		EP-L1		50		70		L2-XP	
					<- reverse ray from stop, forward ray from stop ->				
y	0				0				0
nu				arbitrary angle		arbitrary angle			
u				arbitrary angle		arbitrary angle			
					<- reverse ray from stop, forward ray from stop ->				
y	D_EP/2		D_stop/2		D_stop/2		D_stop/2		D_XP/2
nu				0		0			
u				0		0			

Above is the setup for this problem. Below, I have inputted the appropriate known values then propagated each ray using the YNU raytrace equations.

f			250				400		
t		-62.5		50		70		-84.84848485	
n		1		1		1		1	
`-ϕ			-0.004		0		-0.0025		
t/n				50		70			
					<- reverse ray from stop, forward ray from stop ->				
y	0		-5		0		7		0
nu		0.08		0.1		0.1		0.0825	
u		0.08		0.1		0.1		0.0825	
					<- reverse ray from stop, forward ray from stop ->				
y	12.5		10		10		10		12.12121212
nu		0.04		0		0		-0.025	
u		0.04		0		0		-0.025	

Entrance Pupil: 62.5mm to the right of the first lens with diameter $D_{EP} = 25.0mm$

Exit Pupil: 84.8mm to the left of the second lens with diameter $D_{EP} = 24.2mm$



Gaussian methods

$$Z_{stop} = -70mm$$
$$f_2 = 400mm$$
$$\frac{1}{z'_{XP}} = \frac{1}{z_{stop}} + \frac{1}{f_2}$$
$$z'_{XP} = -84.4mm$$
$$m_{XP} = \frac{z'_{XP}}{z_{stop}} = 1.21$$
$$D_{XP} = m_{XP} D_{stop} = 24.2mm$$

Exit Pupil: 84.4mm to the left of the second lens with a diameter $D_{XP} = 24.2mm$.

$$n = n' = -1$$
$$z_{stop} = 50mm$$
$$f_1 = 250mm$$
$$\frac{n'}{z'EP} = \frac{n}{Z_{stop}} + \frac{1}{f_1}$$
$$z'_{EP} = 62.5mm$$
$$m_{EP} = \frac{z'_{EP}}{Z_{stop}} = 1.25$$
$$D_{EP} = m_{EP} D_{stop} = 25.0mm$$

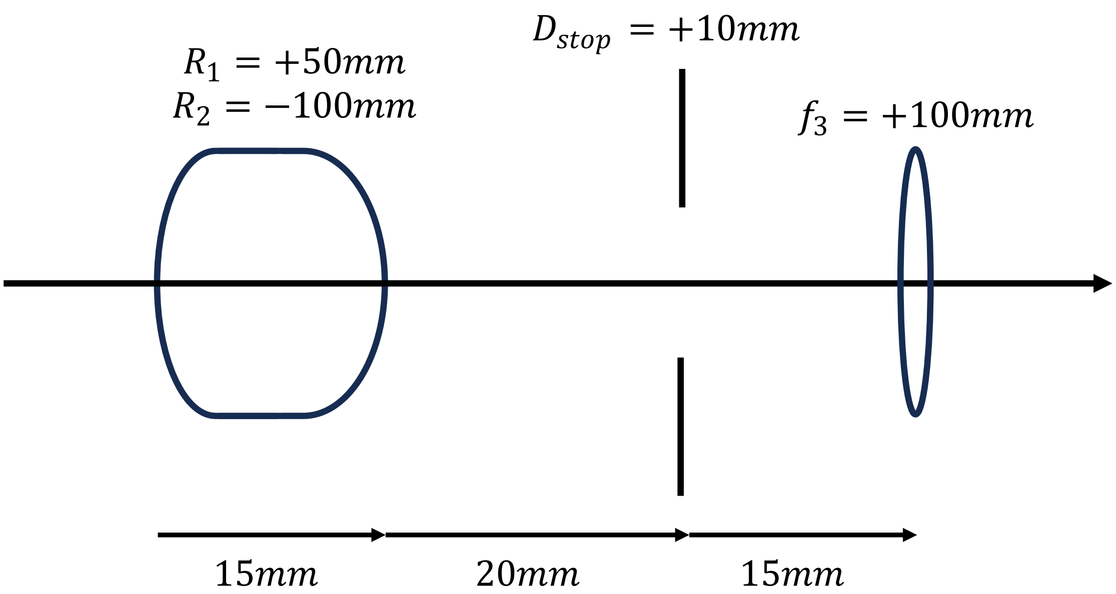
Entrance Pupil: 62.5mm to the right of first lens with a diameter $D_{EP} = 25.0mm$.

2. Paraxial Raytrace

Consider an optical system comprised of a biconvex thick lens ($n = 1.5$) in air, a stop and a thin lens in air. Use paraxial raytrace methods for this problem.

a. Determine the following:

- System focal length
- Back focal distance
- Entrance pupil and exit pupil locations and sizes



Assuming now you are familiar with how a paraxial raytrace is set up, here is the completed raytrace for this question. If you're unsure where a value has come from, review the listed key equations at the beginning of these homework solutions.

The rays traced from the stop location are used to find the entrance and exit pupil diameters and locations; the ray traced forwards from the entrance pupil to the rear focal plane F' is used to determine the BFD, system power and focal length. Both of these raytraces have been fully explained in previous problems and it is assumed you now understand their usage.

	entrance pupil		surface 1		surface 2		stop		lens 3		exit pupil		focal plane
R or f			50		-100				100				
t		-47.54098361		15		20		15		-17.64705882		38.94963684	
n		1		1.5		1		1		1		1	
`-ϕ			-0.01		-0.005				-0.01				
t/n				10		20		15					
							<- reverse ray from stop, forward ray from stop ->						
y	0		-2.9		-2		0		1.5		0		
nu		0.061		0.090		0.100		0.100		0.085			
u		0.061		0.060		0.100		0.100		0.085			
	16.3934						<- reverse ray from stop, forward ray from stop ->				11.7647		
y	8.196721311		4.75		5		5		5		5.882352941		
nu		0.0725		0.025		0		0		-0.05			
u		0.0725		0.016666667		0		0		-0.05			
	forward Ray through F'												
y	10		10		9		6.1		3.925		7.176470588		0
nu		0		-0.1		-0.145		-0.145		-0.18425		-0.18425	
u		0		-0.066666667		-0.145		-0.145		-0.18425		-0.18425	

ϕ	0.01843	mm^-1
f'_R	54.2741	mm
BFD	21.3026	mm

$$f_E = \frac{1}{0.01843} = 54.3mm$$

$$BFD = L_3F' = L_3XP + XPF' = -17.65 + 38.95 = 21.3mm$$

Entrance Pupil: $47.54mm$ to the right of the first surface. Diameter $D_{EP} = 16.4mm$.

Exit Pupil: $17.7mm$ to the left of the thin lens. Diameter $D_{XP} = 11.8mm$.

b. Now the stop diameter of this system is undefined while f-number is defined. The definition of f-number ($f/\#$) in this example is $f/\# = \frac{f_E}{D_{EP}} = 5$ ($D_{EP} =$

$diameter\ of\ entrance\ pupil$). What are the new diameters of the entrance and exit pupils and the stop?

When $f/\# = \frac{f_E}{D_{EP}} = 5 \rightarrow D_{EP} = \frac{54.27mm}{5} = 10.9mm$

We now have a scale-factor of $\frac{10.9}{16.5} = 0.662$ used to scale the new diameters of the stop and the exit pupil. For simplicity of the solution set I have put the presented values to two significant figures. However, I have directly called the unrounded values on excel throughout these solutions and the retrieved values are correct.

$D_{stop} = 0.662 \cdot 10 = 6.6mm$

$D_{XP} = 0.662 \cdot 11.76 = 7.9mm$