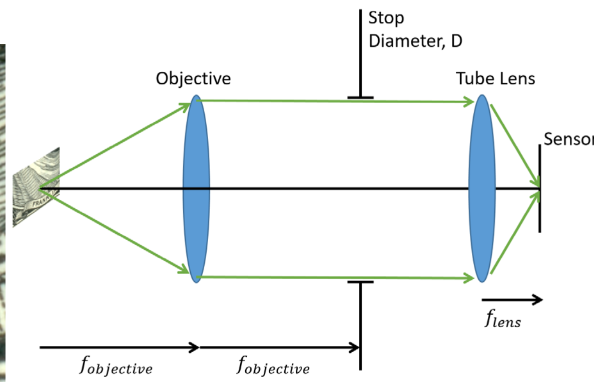
OPTI 415 Midterm March 5, 2020

Answer all three questions

1. Microprinting is a technique for thwarting counterfeiters. The image below shows the words “THE UNITED STATES OF AMERICA” microprinted in Benjamin Franklin’s collar on the $100 bill. The height of these letters is 282 μm. Let’s design an imaging system capable of capturing the image below. The system will consist of an infinity-corrected microscope objective, a tube lens and a digital sensor.



(a) The specs for the digital sensor along with a chart of common sensor sizes are below. Based on this information, what are the horizontal and vertical pixel dimensions of the sensor?

Part Electrical Specifications

Product	Pricing ($/Unit)	Compliance	Status	Type	Megapixels	Frame Rate (fps)	Optical Format	Shutter Type	Pixel Size (μm)	Output Interface	Color	Package Type
AR0330CS1C12SPKA0-CP		Pb-free Halide free	Active	CMOS	3.5	60	1/3 inch	Electronic Rolling	2.2 x 2.2	Multi	RGB	ODCSP-61

Table 1.1 Common CMOS and CCD sensors and their dimensions.

Sensor type	Width (mm)	Height (mm)	Diagonal (mm)
1/10 in.	1.28	0.96	1.60
1/8 in.	1.60	1.20	2.00
1/6 in.	2.40	1.80	3.00
1/4 in.	3.20	2.40	4.00
1/3.6 in.	4.00	3.00	5.00
1/3.2 in.	4.54	3.42	5.68
1/3 in.	4.80	3.60	6.00
1/2.7 in.	5.37	4.04	6.72
1/2.5 in.	5.76	4.29	7.18
1/2 in.	6.40	4.80	8.00
1/1.8 in.	7.18	5.32	8.93
1/1.7 in.	7.60	5.70	9.50
1/1.6 in.	8.08	6.01	10.07
2/3 in.	8.80	6.60	11.00
1 in.	12.80	9.60	16.00

Based on the specs, the sensor has a 1/3" sensor with 2.2 μm square pixels. Based on the chart, a 1/3" sensor has dimensions of 4.8 mm x 3.6 mm. To determine the sensor dimensions in pixels simply divide the dimensions of the sensor by the size of each pixel to get 2182 x 1636 pixels. Based on the F-number and the focal length.

(b) The specification for the system says that a height of 32 pixels are needed to adequately resolve the microprinting. What is the required magnification of the system (don't forget the minus sign)?

The microprinting is 282 μm high and this size times the system magnification m *needs to correspond to 32 pixels on the sensor. Also, we expect the image to be inverted so the magnification is negative. So*

$$m = -\frac{32pix \times 2.2\mu m}{282\mu m} = -0.25$$

(c) What is the focal length of the tube lens if the microscope objective has a focal length of 40mm?

The magnification is given by

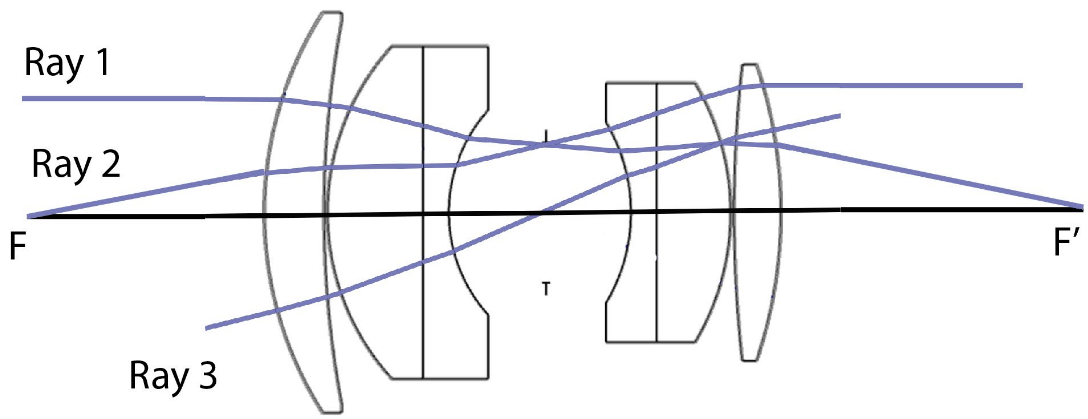
$$m = -\frac{f_{tube}}{f_{objective}} \Rightarrow f_{tube} = 10mm$$

(d) The Numerical Aperture (NA) of the objective is 0.15. What is the diameter of the aperture stop in the objective? (Hint: recall that the $F/\# = 1/2NA$)

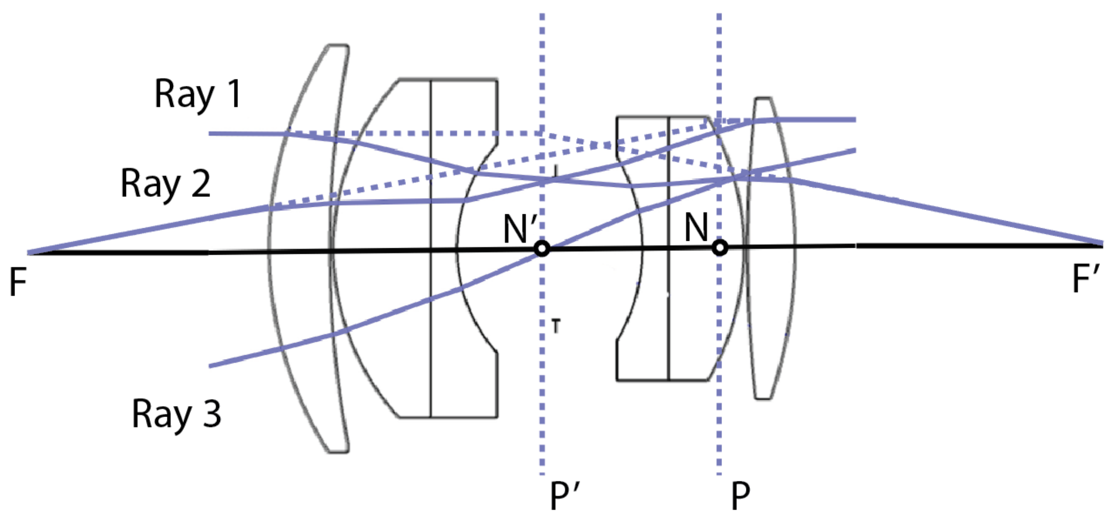
From the hint

$$F/\# = \frac{f_{objective}}{D} = \frac{1}{2NA} \Rightarrow D = 2 \times 0.15 \times 40mm = 12mm$$

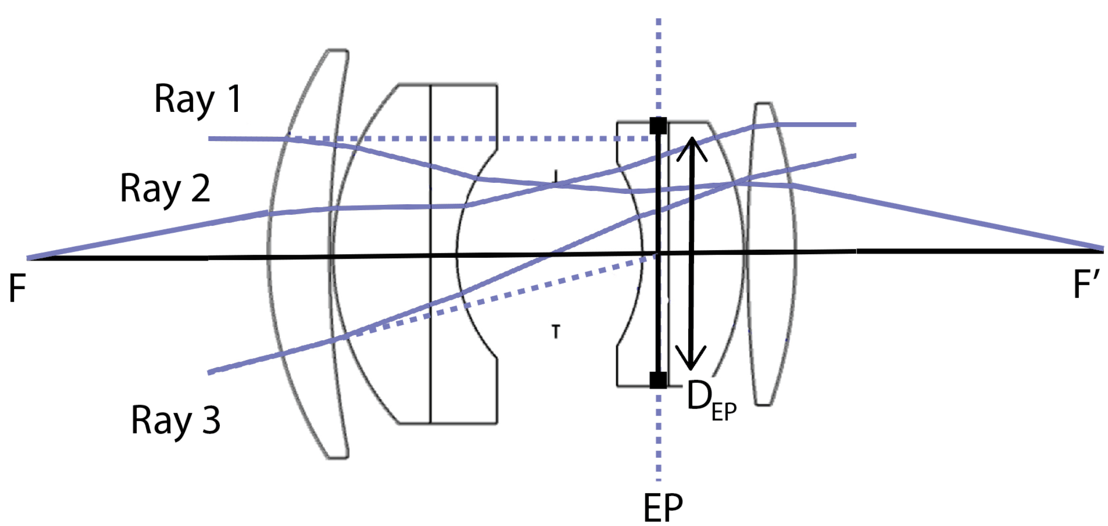
2. The figure below shows a double Gauss lens with three rays traced through it. Ray 1 is parallel to the optical axis as it enters the lens and passes through the edge of the aperture stop. Ray 2 is parallel to the optical axis as it exits the lens and passes through the edge of the aperture stop. Ray 3 passes through the center of the aperture stop. You will be drawing the cardinal points and pupils on the figures below. Be sure to be neat and illustrate how you determine the locations and diameters.



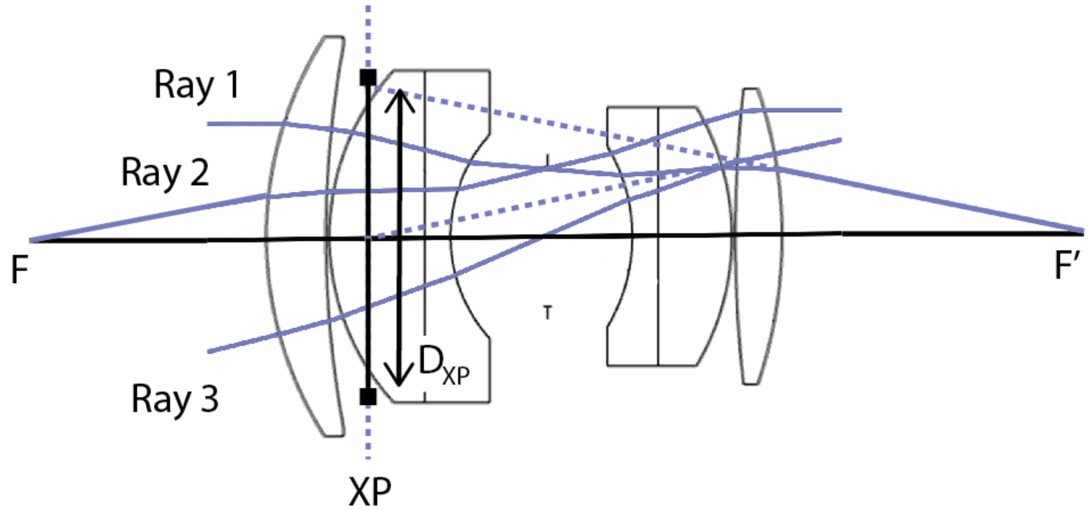
(a) On the figure above, draw the positions of the front and rear focal points and label them F and F', respectively.



(b) On the figure above, draw the front and rear principal planes and label them P and P', respectively. Label the front and rear nodal points N and N', as well.



(c) On the figure above, draw the location and diameter of the entrance pupil. Denote them EP and D_{EP}, respectively.

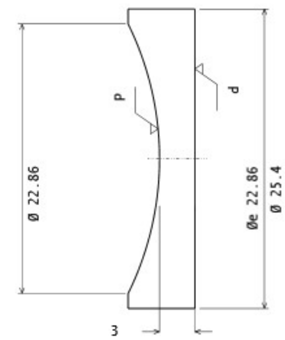


(d) On the figure above, draw the location and diameter of the exit pupil. Denote them XP and D_{XP}, respectively.

(e) Why do we calculate the cardinal points? *Once the cardinal points are determined, the system can be treated as a black box. The image location and magnification can be determined for any arbitrary object without the need to trace additional rays.*

(f) Why do we calculate the entrance and exit pupil locations and size? *The pupils determine how much energy passes through the system. The OPD in the exit pupil describes the aberrations of the optical system.*

3. Sketch the lens specified in the ISO10110 drawing below. Note, the lens is 3 mm thick and has a diameter of $\phi = 25.4\ mm$. Why is $\phi_e < \phi$?



Dimensions in Millimeters

Left Surface	Material	Right Surface
R 25.84 CC	GLASS: N-BK7	R PLANO
Øe 22.86	Nd = 1.516800	Øe 22.86
⊗ EO_VISO_517	Vd = 64.17	⊗
3/ -	0/ -	3/ -
4/ -	1/ -	4/ -
5/ -	2/ -	5/ -
6/ -		6/ -

ISO Element Drawing Indications According to ISO 10110

DATE	SCALE	DRAWN	APPRV	
3/2/2020	2.4000:1			Zemax Zemax OpticStudio 15.5
PROJECT/TITLE 34663 LENS CYL SHAPING 25.4 DIA X -50 FL VIS 0				
PART/DRAWING		REVISION		TEMPSTOK.ZMX Configuration 1 of 1