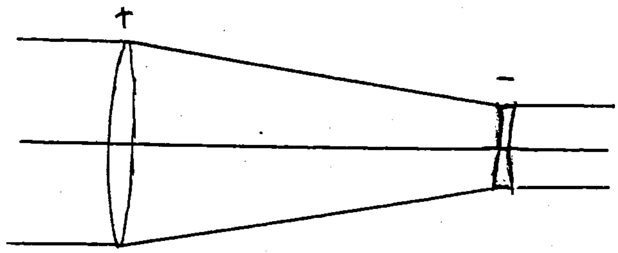
Name Solutions

Closed book; closed notes. An equation sheet is attached and can be removed.
Use the back sides if required. The time limit is 2 hours.
Do not use any pre-stored information or programs in your calculator.
Note any assumptions you make in solving the problems.
Show your work. Present it in a neat and logical fashion.

Thanks for all your efforts this semester. Have a great holiday!!

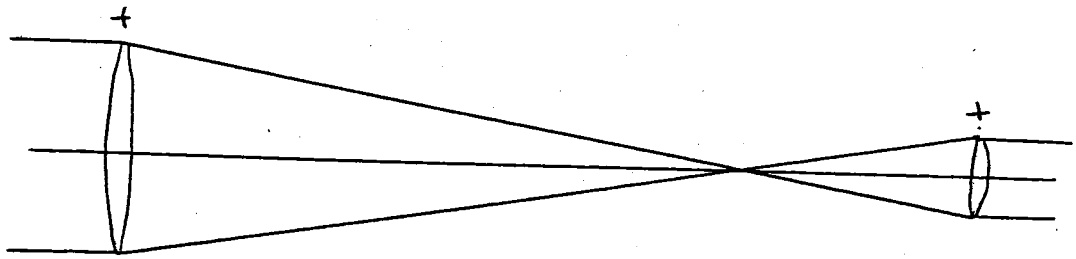
1) (10 points) Sketch a Galilean telescope and a Keplerian telescope. Discuss the relative advantages of each.

Galilean:



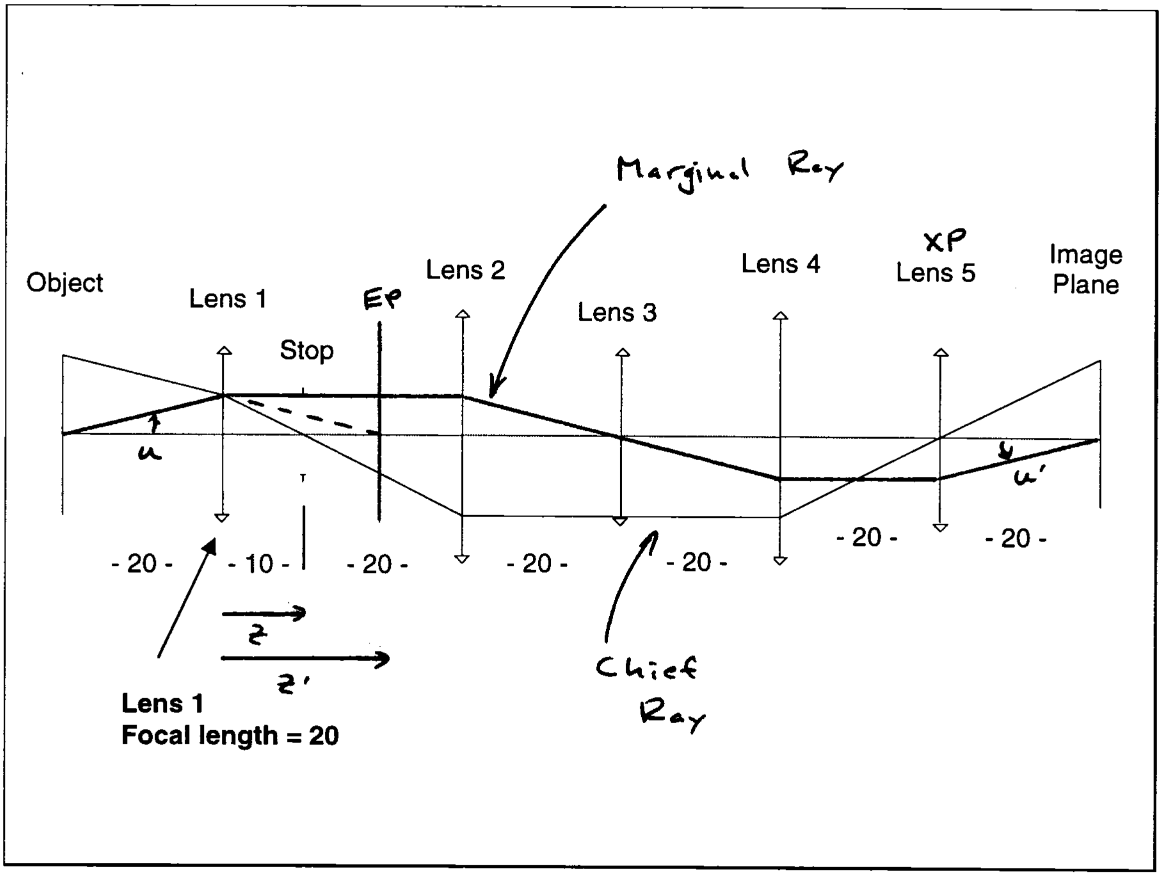
- Positive magnification – erect image
- Shorter for the same |MP|

Keplerian:



- Real exit pupil; positive eye relief
- Intermediate image plane for reticle or field lens
- Wider unvignetted field of view.

2) (30 points) Consider the following optical system that uses ideal, thin lenses to relay an image from the object plane to the image plane. The **chief ray** is drawn. The spacings between elements are given, and the drawing is to scale.



a). Determine the positions of the entrance pupil and the exit pupil.

The chief ray defines the pupil locations

XP: at Lens 5

EP: Graphically - 20 to the right of Lens 1

or Image the stop through Lens 1

$$\frac{-1}{z'} = \frac{-1}{z} + \frac{1}{f_1} \qquad z = 10 \qquad f_1 = 20$$

$z' = 20$ to the right of Lens 1

b) Use the information in the diagram to determine the focal lengths of Lenses 2 – 5.
(Hint – Sketch the marginal ray through the system)

By inspection of the chief ray:

Lens 2 $f_2 = 20$

Lens 3 $f_3 = \infty$ (no ray bending)

Lens 4 $f_4 = 20$

Sketch the Marginal Ray. It must cross the axis at the image plane.

Lens 5 $f_5 = 20$

Note: make use of the ray segments that are parallel to the optical axis.

c) Locate the position of the internal image (a real image formed somewhere other than at the image plane).

At Lens 3

– the marginal ray crosses the axis.

d) Determine the system magnification.

By inspection, $m = +1$

or

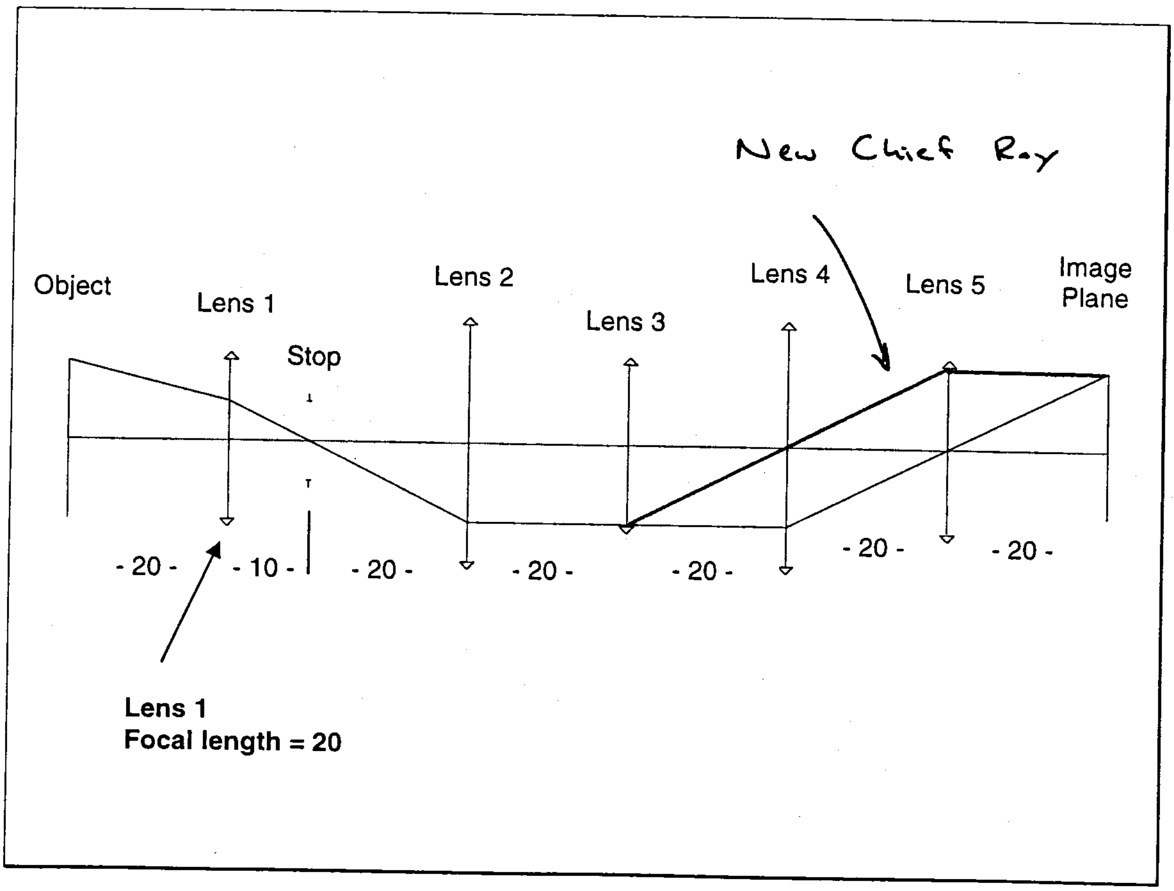
Note that $u = u'$ and $m = \frac{\omega}{\omega'} = \frac{u}{u'} = +1$

e) Change the power of <u>only one lens</u> (no spacing changes) to make this system telecentric in image space, yet maintain the original image position and magnification.

Since Lens 3 is at an image plane (a field lens), changing its power does not change the image size or location.

For image space telecentricity, let $f_3 = 20$

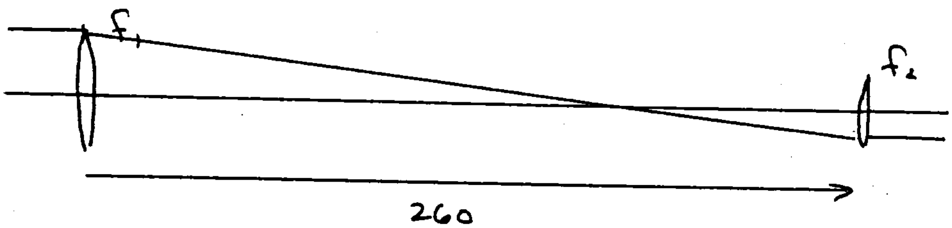
The chief ray is now parallel to the axis in image space.



3) (20 points) A Keplerian telescope has the following specifications:

Magnifying Power = 12 X
Length = 260 mm (objective lens to eye lens)
Eye Relief = 15 mm
All elements are thin lenses

Design the telescope. Provide element focal lengths and spacings. Be sure to verify that all of the above specifications are met exactly.



12X $m = -1/12$

L = 260 mm

$L = f_1 + f_2$ $m = -f_2/f_1$

$f_1 = 240$ mm $f_2 = 20$ mm

Eye relief: image objective through eye lens

$z = -260$ $f_2 = 20$

$\frac{1}{z'} = \frac{1}{z} + \frac{1}{f}$ $z' = 21.67$ mm

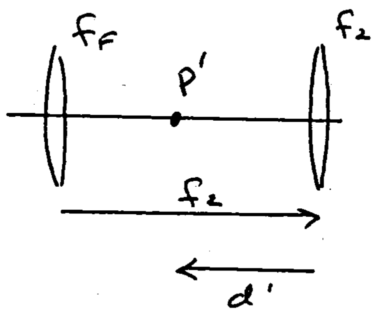
But the required ER is 15 mm. A field lens must be added to shift the rear principal plane of the eyepiece 6.67 mm to the left.

$d' = -6.67$ mm

$\phi = 1/f_2$

$\phi_F = 1/f_F$

$t = f_2$



$d' = -\frac{\phi_F}{\phi} t = -\frac{f_2}{f_F} f_2 = -6.67$ mm

$f_F = 60$ mm

4) (15 points) A 250 mm focal-length thin-lens achromatic doublet is to be designed using BK7 as the low-dispersion element. There are two choices for the high-dispersion element (SF6 or LaK31).

Glass	n_d	υ	P
BK7	1.517	64.2	0.3076
SF6	1.805	25.4	0.2871
LaK31	1.697	56.4	0.3054

In your opinion, which is the better combination (BK7 and SF6 or BK7 and LaK31)? Be sure to justify your answer.

$$\phi = 1/f = 1/250 = .004/mm$$

$$\phi_1/\phi = \frac{\nu_1}{\nu_1 - \nu_2} \qquad \phi_2 = \phi - \phi_1$$

$$\delta\phi_{dC}/\phi = \delta f_{Cd}/f = \frac{\Delta P}{\Delta \nu}$$

BK7/SF6:

$\phi_1 = .0066/mm$ $\quad f_1 = 151$ mm

$\phi_2 = -.0026/mm$ $\quad f_2 = -382$ mm

$\delta\phi_{dC} = .0000021/mm$ $\quad \delta f_{Cd} = .132$ mm

BK7/LaK31:

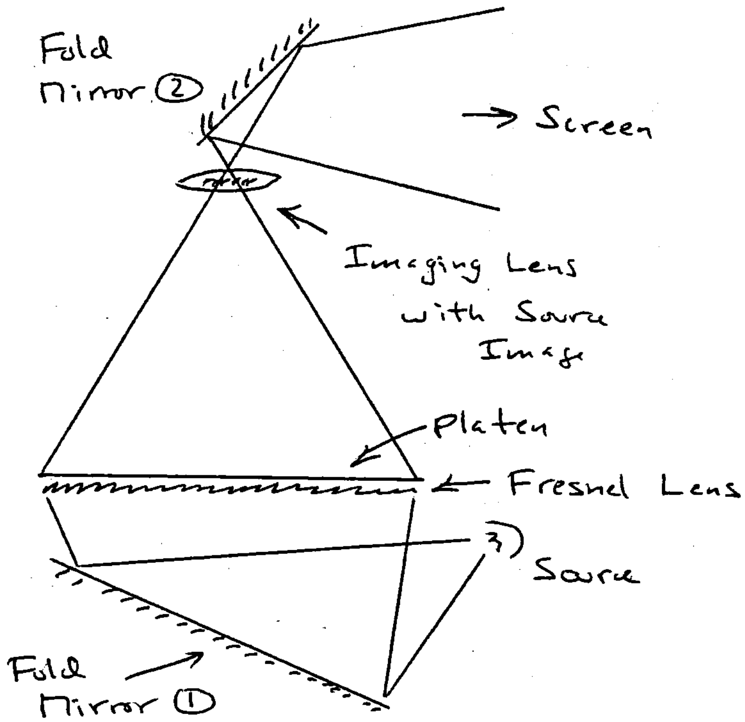
$\phi_1 = .0329/mm$ $\quad f_1 = 30.4$ mm

$\phi_2 = -.0289/mm$ $\quad f_2 = -34.6$ mm

$\delta\phi_{dC} = .0000011/mm$ $\quad \delta f_{Cd} = .071$ mm

While the BK7/LaK31 lens has reduced secondary color, it has significant excess power. In my opinion, the BK7/SF6 combination is the better of the two.

5) (15 points) Sketch the layout of an overhead projector. For each major component, note its purpose and indicate how you would determine its size and/or focal length. Do not design the projector.



Platen - size of the transparency

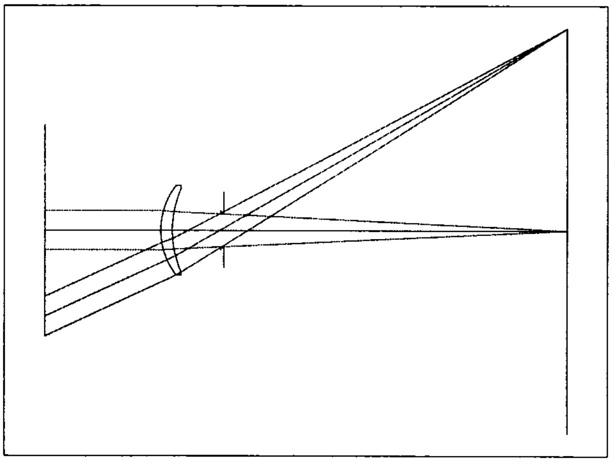
Fresnel Lens - As fast as possible (f/1 or faster). Same size as platen. Images source into imaging lens.

Fold Mirror ① - For compactness. Must allow the source to illuminate the entire platen

Imaging Lens - Images the transparency on the screen. Focal length determined by object/image distance and magnification. Must be larger than the source image.

Fold Mirror ② - Redirects the light "over the shoulder". Provide a necessary parity change. Must not vignette the beam.

6) (15 points) A landscape lens is a common lens configuration for inexpensive and single use cameras. This lens consists of a positive meniscus element with a separated stop. The lens is relatively slow, but its aberrations are well balanced over its field of view.



For the purpose of this problem, we can consider the lens element to be a thin lens. Since the thickness of the thin lens element is zero, and we are only interested in the first order properties of the system, we do not need to discuss the bending of the lens. (The bending of the lens corrects the aberrations of the system.) The object is at infinity.

Focal length	38 mm
Lens to stop separation	5 mm
Stop diameter	3 mm
Maximum image height	+/- 18 mm

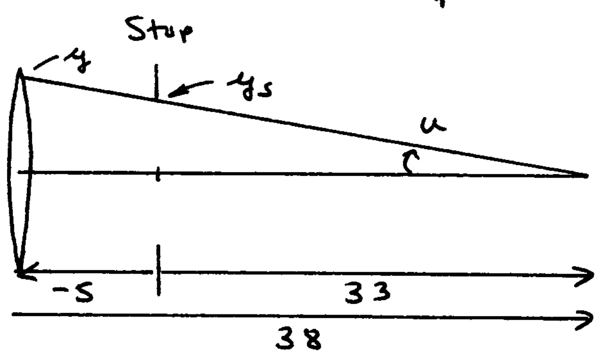
(to match the long dimension of a 35 mm negative)

What is the required lens diameter for the system to be unvignetted over this field of view? Solve the problem using the marginal and chief rays.

Next Page

We need y and $\bar{y}$ at the lens:

$r_{stop} = 1.5\,mm$



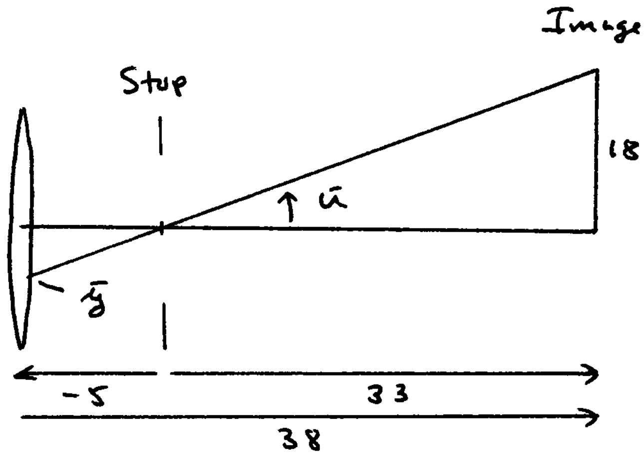
Marginal Ray

$$u = -\frac{r_{stop}}{33} = -\frac{1.5\,mm}{33\,mm}$$

$$u = -.04545$$

$$y = -38\,u$$

$$\underline{y = 1.73\,mm}$$



Chief Ray

$$\bar{u} = \frac{18\,mm}{33\,mm}$$

$$\bar{u} = .5454$$

$$\bar{y} = -5\,\bar{u}$$

$$\bar{y} = -2.73\,mm$$

Unvignetted

$$a \geq |y| + |\bar{y}|$$

$$a \geq 4.46\,mm$$

$$\underline{Dia \geq 8.92\,mm}$$