# LAB 1: MULTIPLE LENS SYSTEMS
# THE ZOOM LENS

This lab is a continuation of our look at the telephoto lens, but with a slightly different twist. Recall that the telephoto lens uses a positive lens (positive focal length $f_1$) in front of a negative lens (negative focal length $f_2$), with the lens-to-lens spacing $t < f_1$. This places the negative lens inside the rear focal point of the positive lens. As a result, the negative lens "sees" a virtual object, and the two-lens system overall forms a real image. The (positive) effective focal length of this combination of lenses is greater than $f_1$ alone, and the back focal distance (BFD) is shorter than for the single positive lens alone.

The following figure illustrates the telephoto lens:

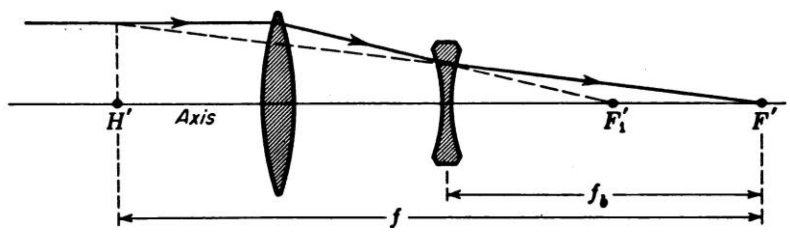



Fig. 1.1. Principles of the telephoto lens.
(from Fundamentals of Optics, Jenkins & White)

Note that when a positive lens is used to image distance objects (objects effectively at infinity), the image size is directly proportional to the focal length of the lens. As the focal length is increased, the image size increases. Given a fixed size of film (or electronic image sensor), this has the effect of "magnifying" the image, or "zooming in" on the object. Hence the name "zoom lens" for a telephoto lens that has variable focal length, **with a fixed image plane**.

**Pre-Lab Questions:**

- **(Q1)** How did a photographer focus the very first, early-day cameras (the kind with the large bellows)? The camera we have in the corner of our 3rd-floor lobby provides the answer!
- **(Q2)** Where was the plate holder located for objects at infinity?
- **(Q3)** Where was the plate holder located for objects close up?
- **(Q4)** Compare this to the use of a telephoto lens in a modern-day camera. What opto-mechanical 'advantage' does the telephoto lens have over the use of a single positive lens of long focal length?

The modern-day design of a telephoto or zoom lens replaces the single lenses with combinations of lenses, to correct for various aberrations. Still, the overall concept is the same—the front "group" of lenses has a (positive) effective focal length $f_1$, and the "rear" group of lenses has a (negative) effective focal length $f_2$. The Guassian-reduced equivalent of these two groups of lenses is still two single lenses of positive and negative power.

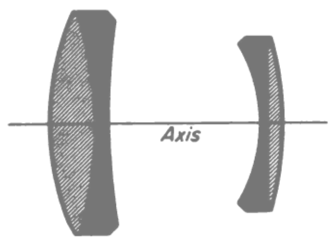



Fig. 1.2. A well-corrected telephoto lens.
(from Fundamentals of Optics, Jenkins & White)

The following figure, Fig. 1.3 (from Lens Design, Milton Laikin) shows a "real-world" zoom lens, designed to have 10X zoom, over the range of 15-150mm focal length. It is designed to operate at F/2.4, providing an image of 16mm in diameter. Note that it was designed for an object at infinity.

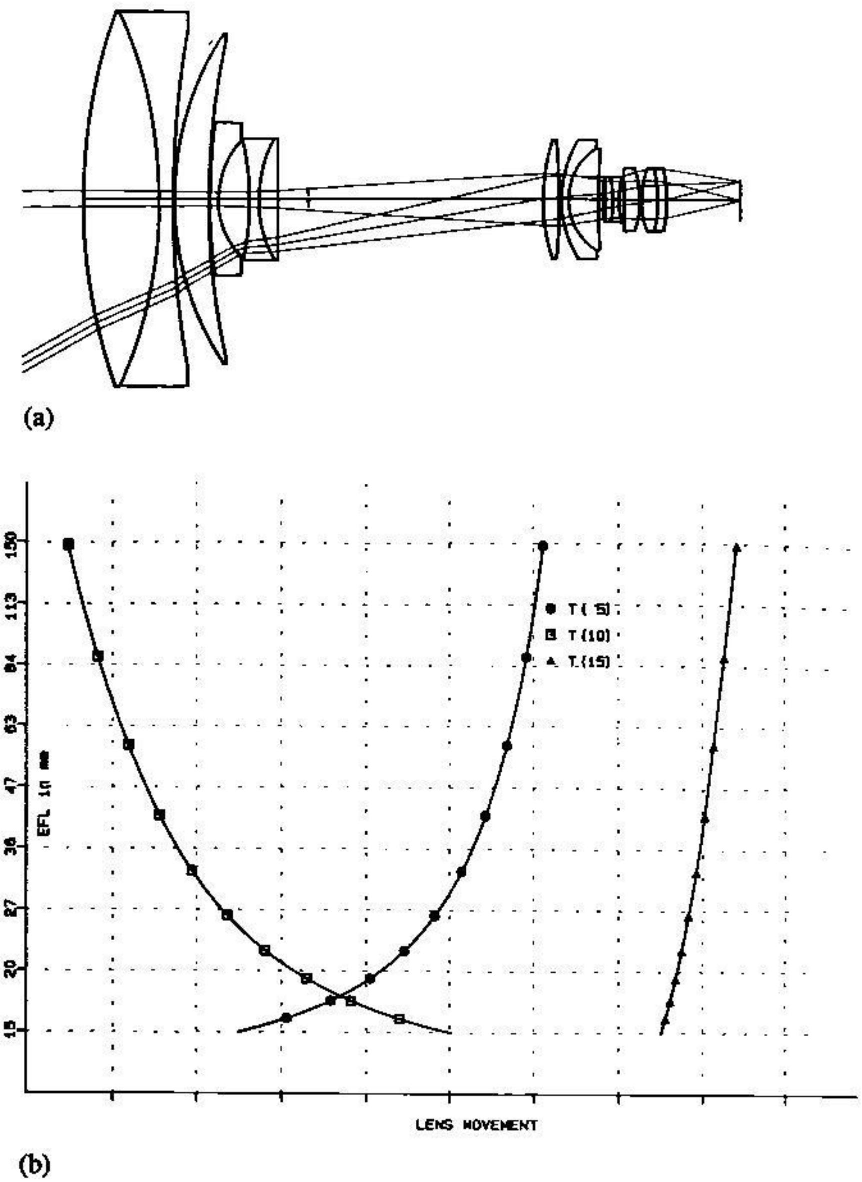



Fig. 1.3. (a) 10X zoom lens: (b) lens movement.
(from Lens Design, Milton Laikin)

Figure 1.4 shows the optical prescription for this lens. Note that T(5) is the thickness (distance) between surfaces 5 and 6, T(10) the distance between surfaces 10 and 11, and T(15) the distance between surfaces 15 and 16.

**Pre-Lab Questions:**

- **(Q5)** How many groups of lenses does the design of this zoom lens use?
- **(Q6)** Which groups move? (note that the front group is stationary).

**Table 35-1** 0.59–5.9 *f*/2.4 10× Zoom Lens

| Radius | Thickness | Diameter | Material |
|---|---|---|---|
| 7.9840 | 1.271 | 5.80 | LAK9 |
| –6.6506 | 0.236 | 5.80 | SF5 |
| 13.8143 | 0.025 | 5.28 | |
| 4.3514 | 0.574 | 5.10 | BAF8 |
| 10.3710 | 0.020 | 5.00 | |
| 8.1222 | 0.142 | 2.36 | LAK9 |
| 1.2218 | 0.532 | 1.80 | |
| –3.7564 | 0.157 | 1.78 | LAK9 |
| 1.7658 | 0.333 | 1.89 | SF5 |
| 0.0000 | 4.541 | 1.89 | |
| 2.7996 | 0.269 | 1.84 | LAKN12 |
| –9.8674 | 0.041 | 1.84 | |
| 1.6338 | 0.118 | 1.85 | SF1 |
| 0.8892 | 0.510 | 1.57 | LAKN12 |
| 12.4418 | 0.083 | 1.57 | |
| Stop | 0.045 | 0.58 | |
| –1.9062 | 0.119 | 0.59 | LAF3 |
| –1.5358 | 0.098 | 0.70 | SF1 |
| 1.1126 | 0.104 | 0.63 | |
| –2.7453 | 0.257 | 0.69 | SF8 |
| –1.3762 | 0.030 | 0.98 | |
| 1.3240 | 0.277 | 0.98 | BAK1 |
| –1.8552 | 0.155 | 0.98 | SF1 |
| –2.0144 | 1.282 | 0.98 | |

**Table 35-2** Focal Length vs. Air Spaces

| EFL | *T*(5) | *T*(10) | *T*(15) | Pupil | Distortion(%) |
|---|---|---|---|---|---|
| 0.591 | 0.020 | 4.541 | 0.083 | –3.804 | –7 |
| 1.272 | 1.720 | 2.649 | 0.274 | –8.814 | –1.8 |
| 2.753 | 2.889 | 1.206 | 0.549 | –16.179 | –0.2 |
| 5.905 | 3.657 | 0.019 | 0.966 | –30.435 | 1 |

Fig. 1.4. Optical design, 10X zoom lens.
(from Lens Design, Milton Laikin)

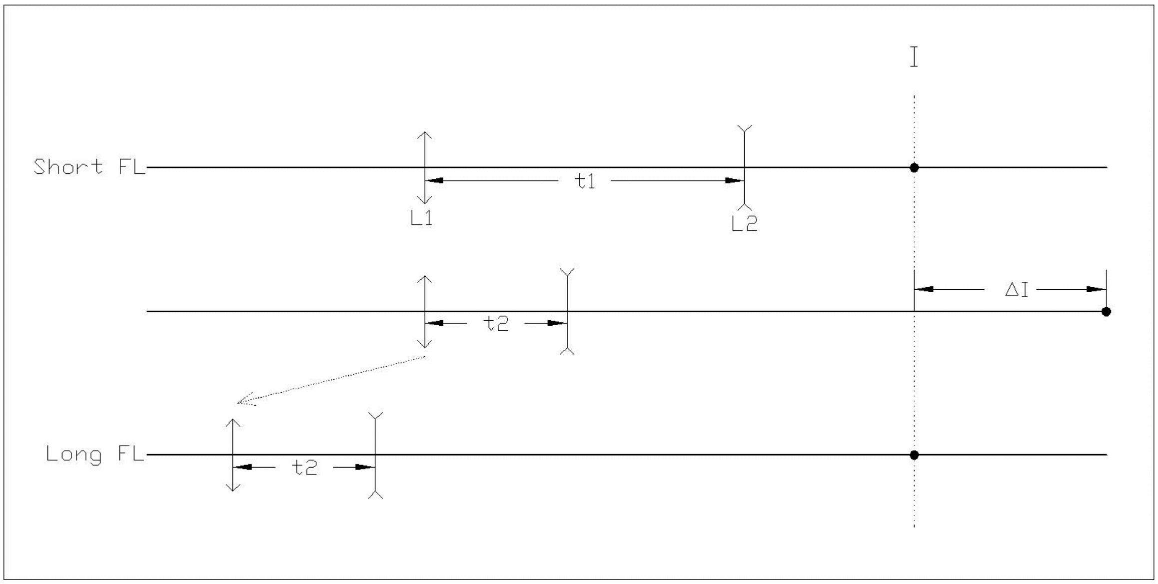
## Two-Lens Paraxial Zoom Design:

## Pre-Lab Questions:

- **(Q7)** Using the following two lenses, do a paraxial design of a zoom system to cover the range of focal lengths from 200-750mm:

$f_1$ = +200mm , lens location at L1
$f_2$ = -150mm , lens location at L2
lens separation = t
image location = I

The following layout shows the lenses in two different positions, to achieve two different focal lengths. Note that the focal plane remains in the same location I:




Approach the design as follows. The lens separation t determines the effective focal length of the telephoto lens. The image location I is designed to be fixed, perhaps on a piece of film or a CCD or CMOS digital sensor chip. As you vary t by amount Δt, the focal length and BFD change. The change in BFD is denoted by ΔI.

To maintain focus at I, **move both of the lenses as a unit a distance equal to ΔI,** so that the new distance between L2 and the image I is equal to the new Back Focal Distance, $BFD_2$.

**(Q7) continued.....**

Detailed approach to the paraxial calculations:

Perform all of the following calculations using a **computer spreadsheet**:

(1) Choose the effective focal length $f_T$
(200-750mm in steps of 25mm)

(2) Calculate t
$t = f_1+f_2-(f_1*f_2/f_T)$

(3) Calculate the BFD
$BFD=f_T*(f_1-t)/f_1$

(4) Fix the position of the image plane I, and calculate the location of the two lenses L1 and L2. Choose I to be at 900mm on the optical rail.

L1=900-BFD-t
L2=900-BFD

(5) Repeat back to step (1).

(6) Plot L1 and L2 vs. $f_T$. Email me your spreadsheet. nofziger@optics.arizona.edu

## Lab Exercises

### (A) Magnification vs. Focal Length:

(1) Auto-collimate a "diffuse pinhole" source (using the ground-glass diffuser).

(2) Replace the pinhole with a transparent ruler (include the diffuser).

(3) Set up a 35mm slide holder with a white screen at the end of the optical rail (at the 900mm tick mark), to mimic the use of photographic film (equivalent to the dimensions of a modern, "full-frame" CMOS electronic sensor). The location of the slide holder defines the image plane and its boundaries act as the **field stop**, limiting the size of the image on the “film" or the "sensor.”

(4) Set up the two lenses for a focal length of 200mm, locating them along the rail according to your pre-lab calculations. Is the image in focus on the screen? If not, double-check your calculations!

For 5 other values of focal length:

(5) Measure the image size. Calculate the magnification.

(6) Describe the effect that changing the focal length has on what you see on the “film.”

### (B) SLR Camera Zoom Behavior:

For this part, we will assume that the SLR zoom camera lens has a positive and a negative group of lenses, with the positive group being towards the object. The question to answer is this--how does each group move as a function of effective focal length? We will answer this by using the nodal slide to make measurements of focal length. (The setting for focal length is continuously variable, and is only marked at certain locations. Use the nodal slide to make accurate measurements of focal length at all settings, including unmarked ones). At the same time, make measurements of the locations of **V** and **V'** (relative to an arbitrary, but fixed, reference location along the optical rail). This data will allow you to plot the relative movement of V and V’ as a function of focal length.

***NOTE: In the following steps, it is vital that you position the camera lens in the v-groove lens holder, and leave it in place. It MUST NOT MOVE WITHIN THE LENS HOLDER during any of the following steps, or your data will be meaningless! In addition, the microscope must be locked down in its holder and must not be moved.***

Use the nodal slide to investigate the behavior of the zoom lens:

(1) Set the object distance of the lens to be at ∞, and <u>keep it there</u>!

(2) Vary the focal length over the zoom range of 28-75mm, in approximately 5 equal steps.

**…..At each of the different focal length settings:**

(3) Measure the focal length, using the nodal slide.

(4) Move the entire nodal slide carrier to the 600mm location on the optical rail. This location is arbitrary, but will be a "home" or reference position to measure the location of the lens vertices in the following steps.

(5) Move the lens to the 5cm position on the nodal slide translation stage. This location is arbitrary, but will be a “home” or reference position to measure the location of the lens vertices in the following steps.

(6) Move the <u>microscope carrier</u> ***(leave the microscope fixed within its holder!!!)*** until **V*** is in focus (use a tiny amount of dust). Record the location of the microscope carrier on the optical rail.

(7) Rotate the entire nodal slide 180°.

(8) Move the <u>microscope carrier</u> ***(leave the microscope fixed within its holder!!!)*** until **V** is in focus (use a tiny amount of dust). Record the location of the microscope carrier on the optical rail.

(9) Change to a new focal length and repeat steps (3)-(8).

(10) Enter your data into a spreadsheet and plot the relative positions of the positive and negative lens groups as a function of focal length.