LAB 6: IDEAL IMAGING

THEORY

When a ray strikes an object, typically it is absorbed and reradiated as many rays (diffuse reflection) Fig. 6.1. If a screen is placed near a diffusely reflecting object, each point on the screen will receive light from many object points, and no image will form Fig. 6.2. To produce an image, rays from any object point should strike only a single point on the screen. The easiest way to effect this condition is by using a pinhole Fig. 6.3.

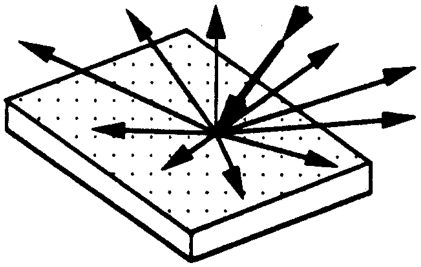

Figure 6.1. Diffuse Reflection

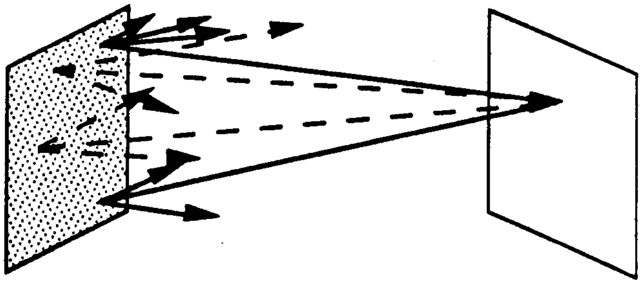

Figure 6.2. Rays from several object points overlap. No image is formed.

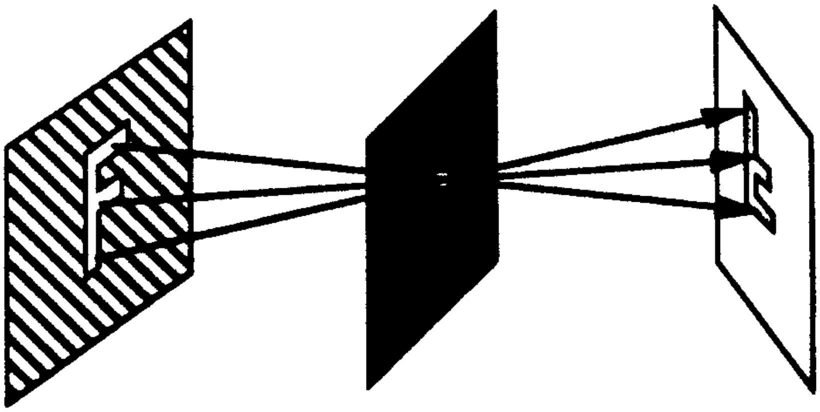

Figure 6.3. Pinhole Imaging

Experiment 6-1: Pinhole Imaging

Place an open or clear aperture in the shape of an "F" in front of the light source. The plain white card serves as an observing screen. Place it on the optical rail next to the “F” aperture and observe it as you move the screen away from the source. Describe what you see.

Now place a ground glass plate behind the "F" aperture. Repeat the experiment. Describe what you see.

- What is the purpose of the ground glass?

Start with the diffuse source (the ground glass plate and the "F" aperture) and the medium-size pinhole with the large card around it. (The large card serves to block any stray light outside of the pinhole from reaching the image plane). Place the pinhole between the source and observing screen and note the inverted image of the source. Vary the distances between the source, pinhole, and screen and qualitatively observe the image. Choose 5 combinations of object and image distances and measure the object and image heights and distances each time. Calculate the appropriate ratios to verify the following formula:

$$\boxed{\text{Magnification} \equiv M_t = m = \frac{\text{Image Height}}{\text{Object Height}} = \frac{\text{Image Distance}}{\text{Object Distance}}}$$

As a variation on this, keep the object distance constant and measure the image height at 10 different image distances. Graph the image distance (y-axis) vs. magnification (x-axis).

- What should the graph look like?
- Does the image form in only certain locations or anywhere behind the pinhole? Explain.
- What is the orientation of the image? Explain.

Finally, substitute the other pinholes and observe the effect of pinhole size on image brightness and sharpness. Describe (qualitatively) your observations.

If the object distance is held constant:

- What happens to image brightness as the image distance is changed?

Image brightness may be thought of as the light energy in the image divided by the image area. (A more correct definition will be given later.) If the object distance is held constant:

- How much will the magnification change if the image distance is doubled?
- How much will the image brightness change if the image distance is doubled?

A lens can also be used to produce a one-to-one correspondence between object and image Fig. 6.4.

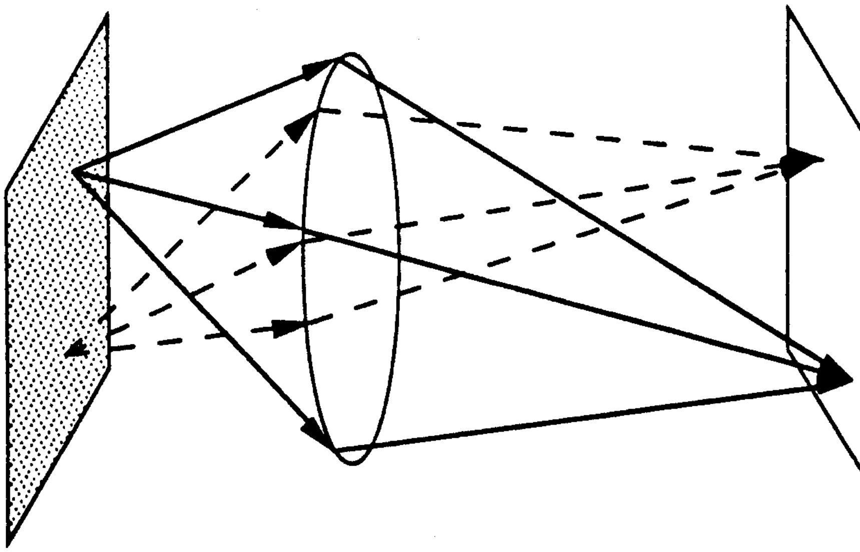

Figure 6.4. Light from different object points does not overlap, as in Fig. 6.2. The result is that an image forms.

Experiment 6-2: Lens Imaging

Replace the pinhole with the biconvex +75 mm focal length lens (KBX058) (the large card is no longer needed). The image no longer forms anywhere behind the lens but only at a specific place. Move the observing screen back and forth along the optical axis to locate the point where the lens reproduces the sharpest or most distinct version of the object. *At this location the lens forms an image, and the image is said to be in focus.* Notice that the image is much brighter than the one formed by the pinhole, but is still inverted.

One of the sources of error in this experiment is that it is difficult to precisely locate the image plane. Very carefully move the screen and notice that there is a region over which a given point in the image appears reasonably sharp. This is called **depth of focus**, and will be considered in more detail later in the lab. For now, locate the image at the point of sharpest focus.

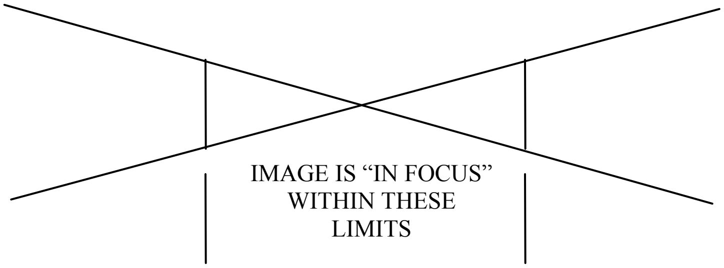

Figure 6.5. Depth of Focus.

- ∗ Measure the image height and image distance for 10 different object distances. Compute the magnifications using the ratios of heights and distances, as in Experiment 6-1.

Consider the formula which relates the object and image distances, s and s′ respectively, to the focal length f of a given lens:

$$\boxed{\frac{n'}{z'} - \frac{n}{z} = \frac{n'}{f^*}} \qquad (6.1)$$

Thus, a graph of n′/z′ vs. n/z should be linear with a y-intercept of n'/f^* (convince yourself of this). Graph your data in this way. (Use units of meters for a better-scaled plot.) "Eyeball" a best-fit straight line to the data, and draw it in. Measure the y-intercept of this best-fit line. Calculate the focal length from this value.

- ∗ How close is your measured value of focal length to the known value of 75.6 mm for this lens? Quote your answer as a % error.
- ∗ Why does the lens form an image at a specific place, vs. the pinhole? Ex plain with a drawing showing a lens and two paraxial rays.
- ∗ Why is the image inverted? Explain using the drawing above.

Experiment 6-3: Image Quality

Use the large surplus lens for this experiment and the same diffuse "F" object. Examine the image formed by this lens. Place a small piece of black tape near the center of the lens. (Generally, you should not place anything on a lens, particularly if it is coated, which is why you are using a cheap lens for this experiment.) Comment qualitatively on the image sharpness, brightness, and magnification with and without the tape. Suppose several small pieces of black tape are randomly distributed over the lens. What will happen to image sharpness, brightness, and magnification? Try it and note the results.

Experiment 6-4: F-Number

The concept of F-number, or F/#, is defined for a lens or mirror, and is usually quoted as an optical specification for that component. For an object at infinity, a (positive/negative) lens produces an image located at its (rear/front) focal point, and the F/# of the lens is defined as:

$$(F/\#)_\infty \equiv \left| \frac{\text{focal length}}{\text{lens diameter}} \right|$$

This is the lens F/# quoted in an optical catalog. Keep in mind this is true only if the beam fills the full opening, or **aperture**, of the lens.

If the aperture is limited in size ("stopped down"), or if the object is not at infinity (the image is no longer at the focal point), then the *beams* in object or image space may be described by an F/#, often called the "working" F/# of the lens.

$$\text{F/\# of beam} = \text{working F/\#} = (F/\#)_w \equiv \frac{L}{D}$$

where L is the distance from an arbitrary plane perpendicular to the beam to the beam's point of divergence or convergence, and D is the beam diameter in the plane. It is a measure of how fast a beam is converging or diverging. The smaller the F/#, the faster the beam converges or diverges. A beam that is collimated has an F/# approaching infinity.

The following examples in Fig. 6.6 should help clarify the concept. In all examples, distances are measured in mm.

- Use the 100mm focal length lens (KBX064) and a diffuse pinhole source to investigate the concept of F/#. The lens diameter is 25 mm. What is the $(F/\#)_\infty$ of the lens?

- Place the lens 200mm from the object. Calculate what the image distance should be and from that, calculate what the working F/# should be in image space. Measure the actual working F/# of the beam in image space. Note the image brightness. Calculate where the lens should be placed to produce a working F/# of 16 in image space. Place the lens there and measure the actual working F/# of the beam in image space. What happened to the image brightness?

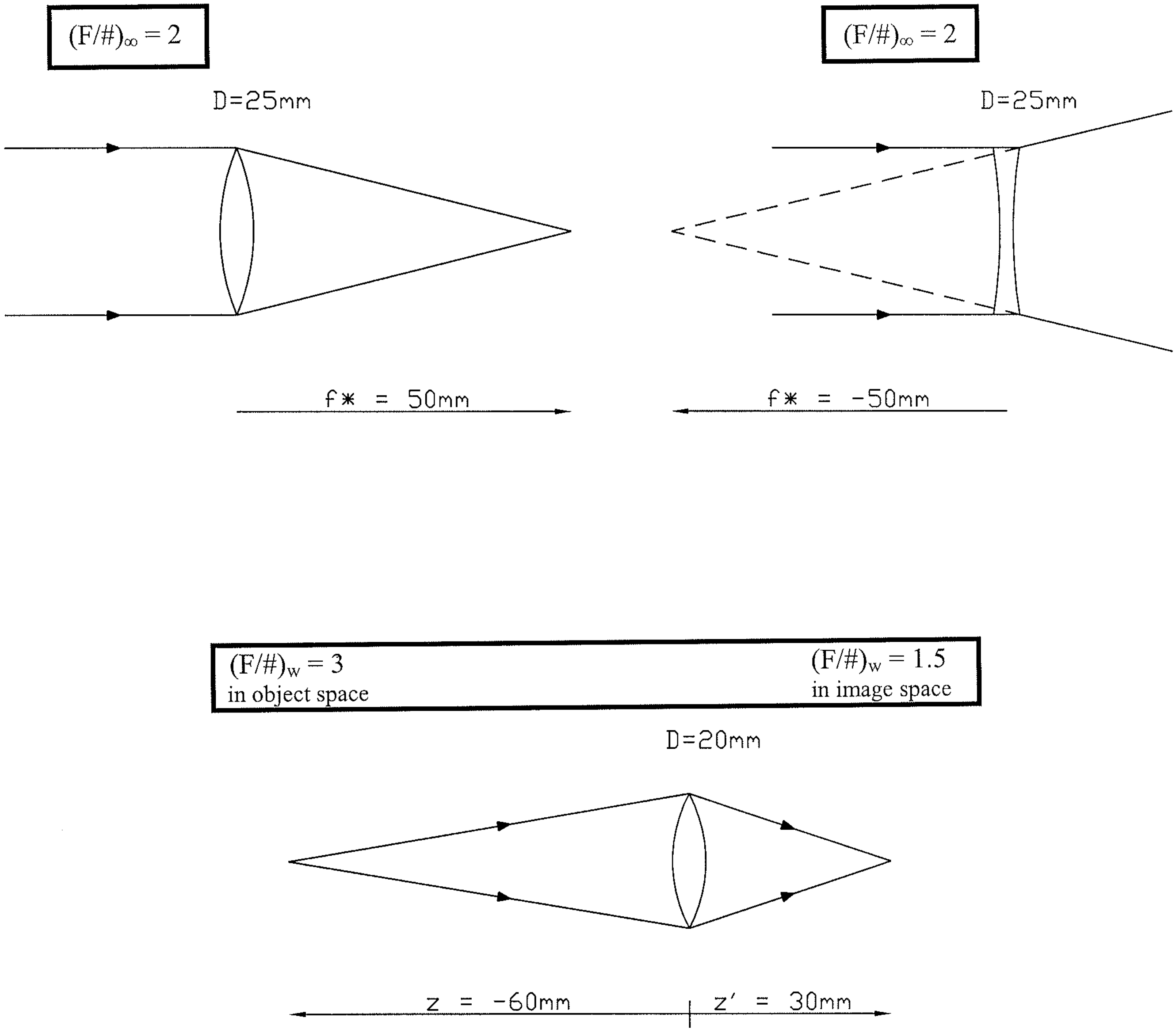

Figure 6.6. The concept of F-Number: $(F/\#)_\infty$ and $(F/\#)_W$.

Experiment 6-5: Depth of Focus

Image the diffuse "F" object with the large-diameter copy lens and locate the best focus using a white card. (Use an object distance of about 500 mm, measured to the center of the copy lens.) Measure the image distance, taken from the center of the lens to the image. Observe and measure the approximate depth of focus (in mm). Stop down the lens by holding the small aperture against the rear vertex. Again, observe and measure the approximate depth of focus.

- Calculate the $(F/\#)_w$ of the beam in each case.
- In a qualitative sense, how does depth of focus vary with the $(F/\#)_w$?
- What was lost (traded off) in the image to obtain a greater depth of focus?