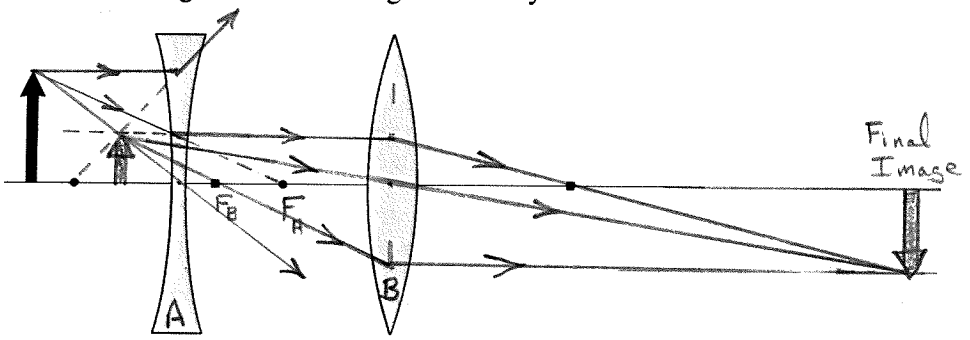
35 Optical Instruments

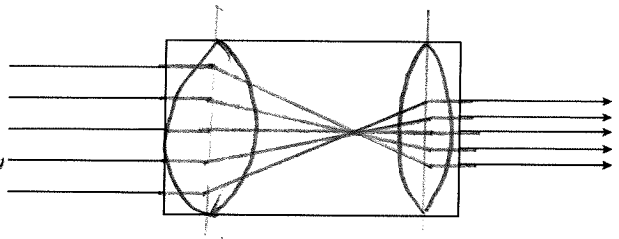
35.1 Lenses in Combination

35.2 The Camera

1. Use ray tracing to locate the final image of the following two-lens system.

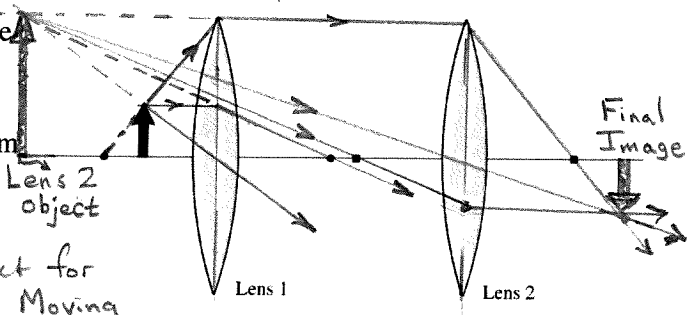


2. Can you tell what's inside the box? Draw one possible combination of lenses inside the box, then show the rays passing through the box.



Two converging lenses is possible, but so is one converging lens plus one diverging lens.

3. Two converging lenses, whose focal points are marked, are placed in front of an object.



   a. Suppose lens 2 is moved a little to the left. Does the final image of this two-lens system move to the left, move to the right, or not move? Explain.

It moves to the left. The object for lens 2 is the image from lens 1. Moving lens 2 closer to its object causes the lens 2 image to be farther away from lens 2 but by an amount less than lens 2 moved. This assumes $s > 2f$ as drawn (and a small move)

   b. With lens 2 in its original position, suppose lens 1 is moved a little to the left. Does the final image of this two-lens system move to the left, move to the right, or not move? Explain.

It moves to the right. As lens 1 moves to the left the image that it produces moves by a greater amount to the right. Thus the object for lens 2 is closer to lens 2 (which has not moved) and so its final image must be farther to the right because the object and image distances add as reciprocals.

4. A photographer focuses his camera on an object. Suppose the object moves closer to the camera. To refocus, should the camera lens move closer to or farther from the detector? Explain.

As the object moves closer to the camera lens, the image moves away from the lens. To refocus, the lens needs to be moved away from the detector to allow for the longer image distance.

5. The aperture of a camera lens has its diameter halved.

   a. By what factor does the *f*-number change?

The f-number increases by a factor of 2.

$$f\text{-number} = \frac{f}{D} \quad \text{so} \quad f\text{-number} \propto \frac{1}{D}$$

   b. By what factor does the focal length change?

The focal length (f) does not change.

   c. By what factor does the exposure time change?

To achieve the same total light energy on the detector (film), the exposure time must increase by a factor of 4 since the light intensity is proportional to the diameter squared.

35.3 Vision

6. Two lost students wish to start a fire to keep warm while they wait to be rescued. One student is hyperopic, the other myopic. Which, if either, could use his glasses to focus the sun's rays to an intense bright point of light? Explain.

The hyperoptic (far-sighted) student uses converging lenses to correct his vision for nearby objects, so his lenses could also focus light from a distant source. The myopic student's lenses are diverging.

7. Suppose you wanted special glasses designed to let you see underwater, without a face mask. Should the glasses use a converging or diverging lens? Explain.

Because of the larger refractive index of water compared to air, you would need a strongly converging lens to assist your eyes in compensation for the small refractive index difference between water and your eye.

35.4 Optical Systems That Magnify

8. a. The angular magnification of a lens is not sufficient. To double the angular magnification, do you want a lens with twice the focal length or half the focal length? Explain.

Half the focal length.

$$M = \frac{25\,\text{cm}}{f}$$

b. Does doubling the angular magnification also double the lateral magnification? Explain.

Generally no. Angular magnification depends only on f, but lateral magnification depends on s and s' (or s and f).

9. For a telescope, increasing the focal length of the objective increases the overall magnification. For a microscope, increasing the focal length of the objective decreases the overall magnification. Why are they different?

For the microscope, the image distance is fixed by the tube length, and since the object is beyond the objective focal length, a longer focal length leads to a longer object distance and smaller magnification. For a telescope, the object is at infinity, and the intermediate image is at the objective focal length, so a longer focal length gives greater magnification.

35.5 Color and Dispersion

10. A beam of white light from a flashlight passes through a red piece of plastic.
    a. What is the color of the light that emerges from the plastic?

Red

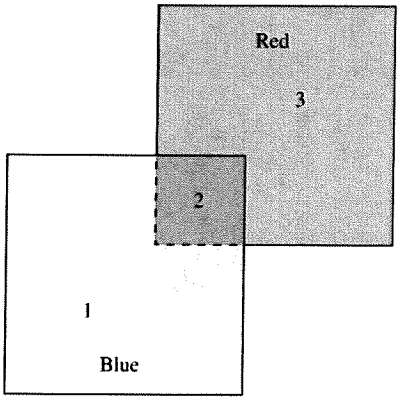
    b. Is the emerging light as intense as, more intense than, or less intense than the white light?

Less intense

    c. The light then passes through a blue piece of plastic. Describe the color and intensity of the light that emerges.

No light emerges

11. Suppose you looked at the sky on a clear day through pieces of red and blue plastic oriented as shown. Describe the color and brightness of the light coming through sections 1, 2, and 3.

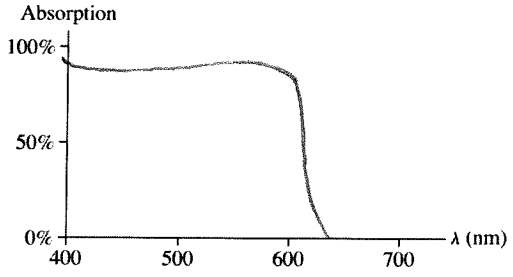


Section 1: Blue. All other colors are absorbed. Less bright.

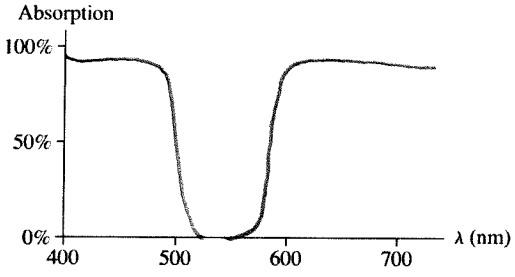
Section 2: Black. Light does not pass through section.

Section 3: Red. All other colors are absorbed. Less bright.

12. Sketch a plausible absorption spectrum for a patch of bright red paint.



13. Sketch a plausible absorption spectrum for a piece of green plastic.



35.6 The Resolution of Optical Instruments

14. A diffraction-limited lens can focus light to a 10-μm-diameter spot on a screen. Do the following actions make the spot diameter larger, smaller, or leave it unchanged?

a. Decreasing the wavelength of the light: Smaller

b. Decreasing the lens diameter: larger

c. Decreasing the lens focal length: larger (out of focus)

d. Decreasing the lens-to-screen distance: larger (out of focus)

15. An astronomer is trying to observe two distant stars. The stars are marginally resolved when she looks at them through a filter that passes green light near 550 nm. Which of the following actions would improve the resolution? Assume that the resolution is not limited by the atmosphere.

a. Changing the filter to a different wavelength? If so, should she use a shorter or a longer wavelength?

She would obtain better resolution with a shorter wavelength. $\theta_{min} = \frac{1.22\lambda}{D}$

b. Using a telescope with an objective lens of the same diameter but a different focal length? If so, should she select a shorter or a longer focal length?

Changing the focal length only will not improve the resolution.

c. Using a telescope with an objective lens of the same focal length but a different diameter? If so, should she select a larger or a smaller diameter?

Larger diameter leads to better resolution.

d. Using an eyepiece with a different magnification? If so, should she select an eyepiece with more or less magnification?

Changing only the magnification will not improve the resolution.