19 Optical Instruments

19.1 The Camera

1. 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 lens, the image is formed farther from the lens, so the lens should be moved away from the detector to keep the image on the detector.

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

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

The f-number increases by 2x.

b. By what factor does the focal length change?

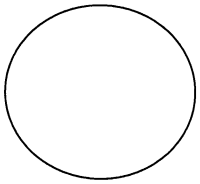
The focal length is unchanged, but the depth of field is greater.

c. By what factor does the exposure time change?

The exposure time increases by 4x because the area of light collection is proportional to the diameter squared. Dropping that area by 1/4 requires a 4x longer exposure to collect the same total amount of light.

3. A camera iris diaphragm set to *f*/4 is shown.

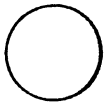
f/4



a. In the spaces provided, redraw the iris opening for the given *f*-stop if the same lens is used:

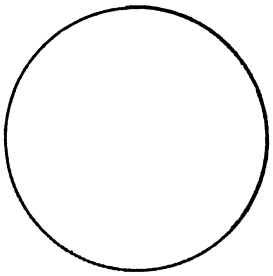
i. *f*/8

Two stops more closed, decreasing the diameter by 1/2.



ii. *f*/2.8.

One stop more open, increasing the diameter by $\sqrt{2}$.



b. Assuming equal illumination is required in each case, rank the diaphragm settings above, from greatest to least, in terms of the shutter speed required. Note that a greater shutter speed corresponds to a smaller amount of time exposure for the image.

Order: $f/2.8 > f/4 > f/8$

Explanation:

Because f/2.8 lets in more light, the time exposure for equal illumination must be less, corresponding to a greater shutter speed.

19.2 The Human Eye

4. The human eye and a camera have many similarities, but one difference is how they focus.
   a. What parameter of a camera is adjusted to keep the image focused on the detector as an object moves away from the camera? Is this parameter increased or decreased? Explain.

As the object is moved away, the image must be formed closer to the lens. To make sure the image is formed on the film, the lens is moved towards the film to decreased the lens-film distance.

   b. What parameter of your eye is adjusted to keep the image focused on the retina as an object moves away from you? Is this parameter increased or decreased? Explain.

Because the length of the eye is fixed, the focal length of the eye is increased as the object is moved away so that the image remains at the back of the retina.

5. 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.

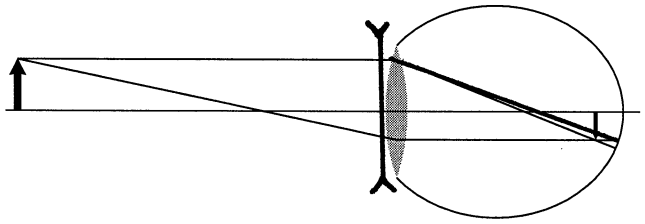
The hyperoptic student. His contact lenses are converging lenses. The myopic student's glasses would cause the light to diverge.

6. 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.

Converging lens. The difference in refractive index between the water and the eye is much less than that between the air and the eye. With a smaller refractive index difference, you need more curvature to focus the light on the retina.

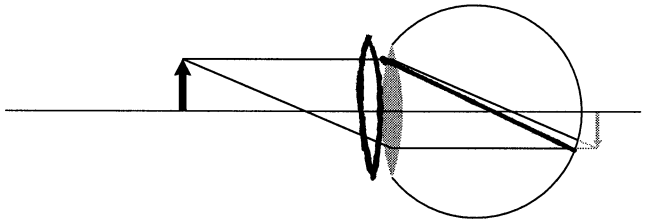
7. Equip each eyeball below with an appropriate eyeglass lens that will produce a well-focused image on the retina. To do so, first draw the lens in front of the eye, then redraw the two rays from the point at which they enter the lens until they form an image.

a.



b. Is this eye hyperopic or myopic? myopic Explain. This is nearsightedness. The eyeball is too long, so the image distance needs to be increased.

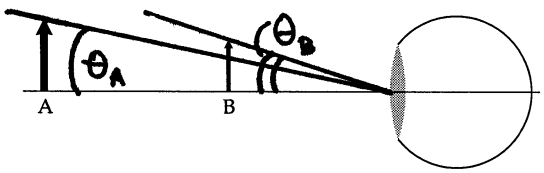
c.



d. Is this eye hyperopic or myopic? hyperopic Explain. This is farsightedness. The eye ball is too short and the image distance needs to be decreased.

19.3 The Magnifier

8. An eye views objects A and B.



a. Which object has the larger size? Explain.

A>B, 1cm > ~0.7cm

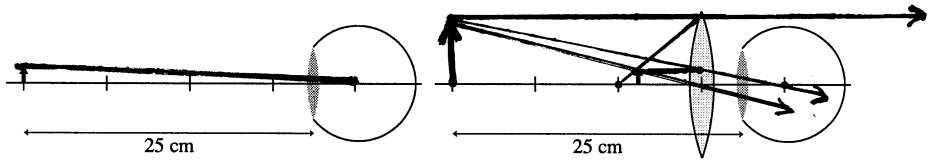
b. Which object has the larger angular size? Explain.

$\theta_B > \theta_A$ See angles marked on sketch.

9. 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. $m = \frac{25\text{cm}}{f}$

10. On the left, an eye observes an object at the eye's near point of 25 cm. This is the closest the object can be and still be seen clearly. On the right, the eye views the same object through a magnifying lens. The object's physical distance from the eye is now much less than 25 cm.



a. Using a straight edge, draw a line on the left figure to indicate the angular size of the object when viewed by the unaided eye at the eye's near point.

b. Use ray tracing with a straight edge to show that the image in the right figure is a virtual image $\approx$ 25 cm from the eye.

c. Draw a line (or label one of your ray-tracing lines) to indicate the angular size of the image seen through the lens.

d. Using a ruler to make measurements, determine the angular magnification of the lens.

Either compare $\tan\theta_1 \approx \frac{2\text{mm}}{38\text{mm}}$, $\tan\theta_2 \approx \frac{8\text{mm}}{38\text{mm}}$ so $m = \frac{8}{2} = 4\text{x}$

or note that the object in the second case is ~.75 units from the lens, so $m = \frac{3}{.75} = 4$

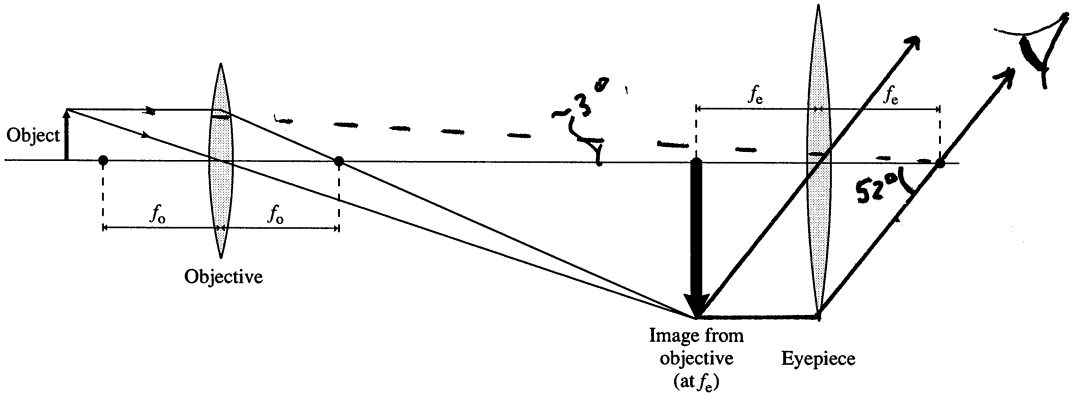
e. It's sometimes said that a magnifying glass makes an object "appear closer." Is that what's happening here? Explain.

When an object is closer, it takes up a larger angular size. Although the magnified image is farther away, it takes up a larger angular size than the object would at that distance so, it appears closer.

19.4 The Microscope

19.5 The Telescope

11. a. Complete the ray diagram by drawing two principal rays to show how the eyepiece affects light from the intermediate image of the objective. Show that the two rays are parallel on the right side of the eyepiece. (Because these rays are parallel, it is not possible to draw the final virtual image on your diagram.)



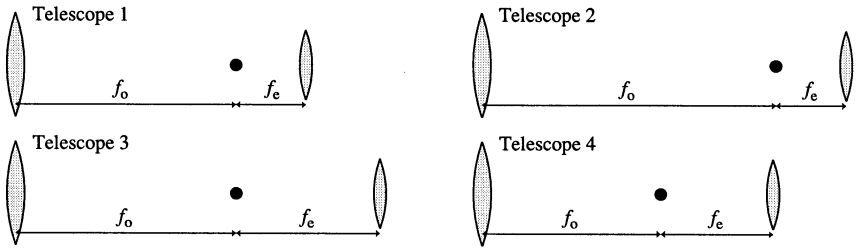
b. On your diagram above, indicate the angle subtended by the final image. This is the image's angular size. Measure this angle with a protractor.
θ final image = 52°

c. Use a red pencil to draw a line from the location of the observer to the tip of the object. Indicate the angular size of the original object and measure this angle with a protractor.
θ object = ~3.°

d. What is the magnification of the two-lens system?

$\frac{\theta}{\theta_o} \sim 16\times$

12. Rank in order, from largest to smallest, the magnifications M_1 to M_4 of these telescopes.



Order: $m_2 > m_1 > m_3 \approx m_4$

Explanation:
The magnification is determined by the ratio f_o/f_e, not the distance between the lenses or the lens diameters.

19.6 Color and Dispersion

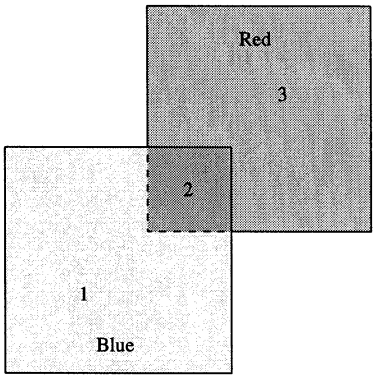
13. A beam of white light from a flashlight passes through a red piece of plastic.
    a. What is the color of the light that emerges from the plastic? Red
    b. Is the emerging light as intense as, more intense than, or less intense than the white light? Explain.

Less intense. Most of the light that is not red has been absorbed.

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

No light emerges because the blue piece absorbs the remaining red light.

14. 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.

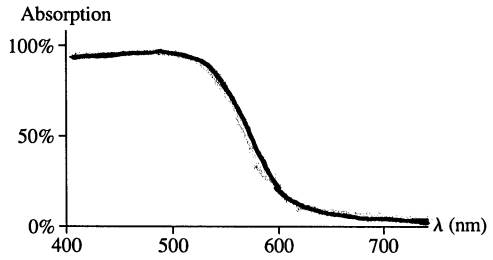


Section 1: Blue. The red end of the spectrum is largely absorbed.

Section 2: Black (grey). Little light gets through both filters.

Section 3: Red. The blue end of the spectrum is largely absorbed.

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



19.7 Resolution of Optical Instruments

16. 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 light: Smaller

b. Decreasing the lens diameter: larger

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

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

17. 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. $\theta_1 = \frac{1.22\lambda}{D}$

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

It will not make a difference.

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?

It will not make a difference, Magnification is not a factor in resolution.

18. The focusing ability of a lens is limited by chromatic aberration. Is the focusing ability of a spherical mirror also limited by chromatic aberration? Explain.

No. There is no dispersion in reflection where $\theta_{refl} = \theta_{inc}$ is the same for all wavelengths.