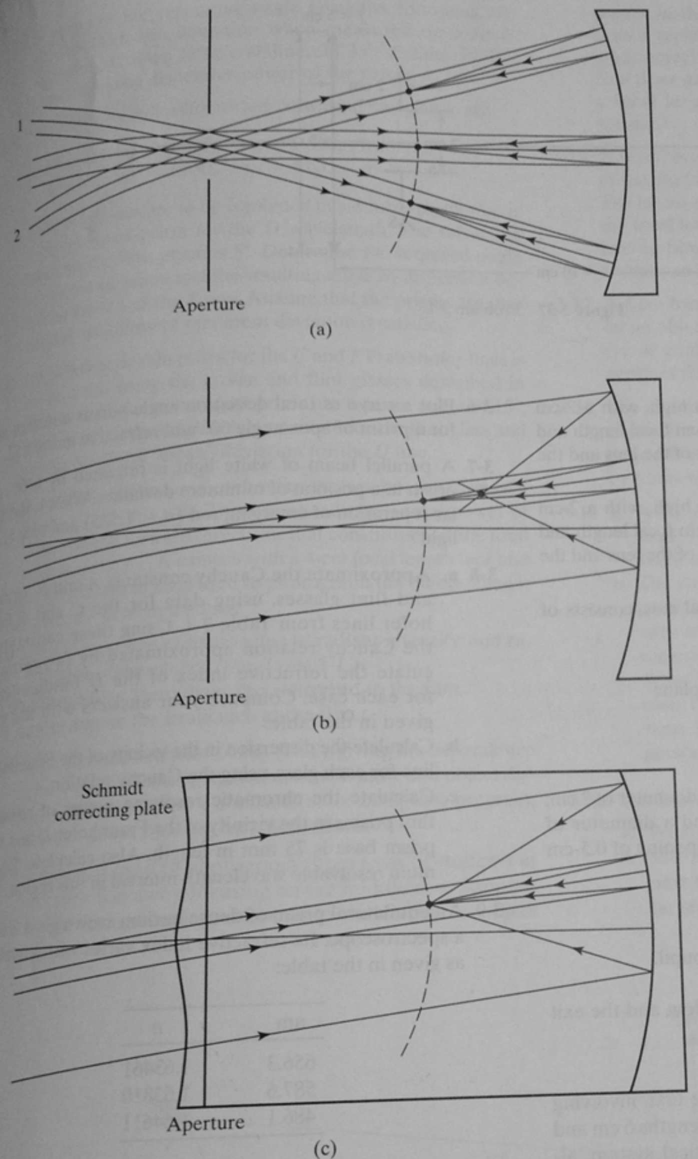

Figure 3-36 The Schmidt optical system.

PROBLEMS

3-1 An object measures 2 cm high above the axis of an optical system consisting of a 2-cm aperture stop and a thin convex lens of 5-cm focal length and 5-cm aperture. The object is 10 cm in front of the lens and the stop is 2 cm in front of the lens. Determine the position and size of the entrance and exit pupils, as well as the image. Sketch the chief ray and the two extreme rays through the optical system, from the top of the object to its conjugate image point.

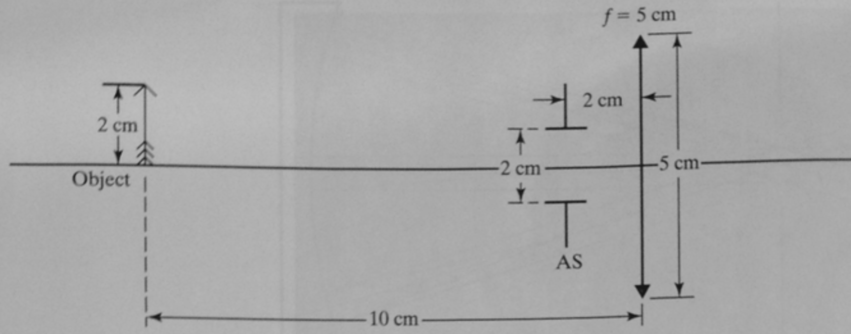

Figure 3-37 Problem 3-1.

3-2 Repeat problem 3-1 for an object 4 cm high, with a 2-cm aperture stop and a thin convex lens of 6-cm focal length and 5-cm aperture. The object is 14 cm in front of the lens and the stop is 2.50 cm behind the lens.

3-3 Repeat problem 3-1 for an object 2 cm high, with a 2-cm aperture stop and a thin convex lens of 6-cm focal length and 5-cm aperture. The object is 14 cm in front of the lens and the stop is 4 cm in front of the lens.

3-4 An optical system, centered on an optical axis, consists of (left to right)

1. Source plane
2. Thin lens L_1 at 40 cm from the source plane
3. Aperture A at 20 cm farther from L_1
4. Thin lens L_2 at 10 cm farther from A
5. Image plane

Lens L_1 has a focal length of 40/3 cm and a diameter of 2 cm; lens L_2 has a focal length of 20/3 cm and a diameter of 2 cm; aperture A has a centered circular opening of 0.5-cm diameter.

a. Sketch the system.
b. Find the location of the image plane.
c. Locate the aperture stop and entrance pupil.
d. Locate the exit pupil.
e. Locate the field stop, the entrance window, and the exit window.
f. Determine the angular field of view.

3-5 Refer back to the extended example in the text, involving both a positive and a negative lens, of focal lengths 6 cm and −10 cm, respectively. For the identical optical system, already partially analyzed,

a. Determine the location and size of the field stop, FS.
b. Determine the location and size of the entrance and exit windows.
c. Using the chief ray from object point P to image point P'' as shown in the example, draw the two marginal rays from P to P'', which, with the chief ray, define the cone of light that successfully gets through the optical system.

3-6 Plot a curve of total deviation angle versus entrance angle for a prism of apex angle 60° and refractive index 1.52.

3-7 A parallel beam of white light is refracted by a 60° glass prism in a position of minimum deviation. What is the angular separation of emerging red ($n = 1.525$) and blue (1.535) light?

3-8 **a.** Approximate the Cauchy constants A and B for crown and flint glasses, using data for the C and F Fraunhofer lines from Table 3-1. Using these constants and the Cauchy relation approximated by two terms, calculate the refractive index of the D Fraunhofer line for each case. Compare your answers with the values given in the table.
b. Calculate the dispersion in the vicinity of the Fraunhofer D line for each glass, using the Cauchy relation.
c. Calculate the chromatic resolving power of crown and flint prisms in the vicinity of the Fraunhofer D line, if each prism base is 75 mm in length. Also calculate the minimum resolvable wavelength interval in this region.

3-9 An equilateral prism of dense barium crown glass is used in a spectroscope. Its refractive index varies with wavelength, as given in the table:

nm	n
656.3	1.63461
587.6	1.63810
486.1	1.64611

a. Determine the minimum angle of deviation for sodium light of 589.3 nm.
b. Determine the dispersive power of the prism.
c. Determine the Cauchy constants A and B in the long wavelength region; from the Cauchy relation, find the dispersion of the prism at 656.3 nm.
d. Determine the minimum base length of the prism if it is to resolve the hydrogen doublet at 656.2716- and 656.2852-nm wavelengths. Is the project practical?

3-10 A prism of 60° refracting angle gives the following angles of minimum deviation when measured on a spectrometer: C line, 38°20′; D line, 38°33′; F line, 39°12′. Determine the dispersive power of the prism.

3-11 The refractive indices for certain crown and flint glasses are

Crown: $n_C = 1.527$, $n_D = 1.530$, $n_F = 1.536$
Flint: $n_C = 1.630$, $n_D = 1.635$, $n_F = 1.648$

The two glasses are to be combined in a double prism that is a direct-vision prism for the D wavelength. The refracting angle of the flint prism is 5°. Determine the required angle of the crown prism and the resulting angle of dispersion between the C and the F rays. Assume that the prisms are thin and the condition of minimum deviation is satisfied.

3-12 An achromatic thin prism for the C and F Fraunhofer lines is to be made using the crown and flint glasses described in Table 3-1. If the crown glass prism has a prism angle of 15°, determine (a) the required prism angle for the flint glass and (b) the resulting "mean" deviation for the D line.

3-13 A perfectly diffuse, or *Lambertian*, surface has the form of a square, 5 cm on a side. This object radiates a total power of 25 W into the forward directions that constitute half the total solid angle of 4π. A camera with a 4-cm focal length lens and stopped down to $f/8$ is used to photograph the object when it is placed 1 m from the lens.

a. Determine the radiant exitance, radiant intensity, and radiance of the object. (See Table 1-1.)
b. Determine the radiant flux delivered to the film.
c. Determine the irradiance at the film.

3-14 Investigate the behavior of Eq. (3-32), giving the dependence of the depth of field on aperture, focal length, and object distance. With the help of a calculator or computer program, generate curves showing each dependence.

3-15 A camera is used to photograph three rows of students at a distance 6 m away, focusing on the middle row. Suppose that the image defocusing or blur circles due to object points in the first and third rows is to be kept smaller than a typical silver grain of the emulsion, say 1 μm. At what object distance nearer and farther than the middle row does an unacceptable blur occur if the camera has a focal length of 50 mm and is stopped down to an $f/4$ setting?

3-16 A telephoto lens consists of a combination of two thin lenses having focal lengths of +20 cm and −8 cm, respectively. The lenses are separated by a distance of 15 cm. Determine the focal length of the combination, distance from negative lens to film plane, and image size of a distant object subtending an angle of 2° at the camera.

3-17 A 5-cm focal length camera lens with $f/4$ aperture is focused on an object 6 ft away. If the maximum diameter of the circle of confusion is taken to be 0.05 mm, determine the depth of field of the photograph.

3-18 The sun subtends an angle of 0.5° at the earth's surface, where the irradiance is about 1000 W/m^2 at normal incidence. What is the irradiance of an image of the sun formed by a lens with diameter 5 cm and focal length 50 cm?

3-19 **a.** A camera uses a convex lens of focal length 15 cm. How large an image is formed on the film of a 6-ft-tall person 100 ft away?
b. The convex lens is replaced by a telephoto combination consisting of a 12-cm focal length convex lens and a concave lens. The concave lens is situated in the position of the original lens, and the convex lens is 8 cm in front of it. What is the required focal length of the concave lens such that distant objects form focused images on the same film plane? How much larger is the image of the person using this telephoto lens?

3-20 The lens on a 35-mm camera is marked "50 mm, 1:1.8."
a. What is the maximum aperture diameter?
b. Starting with the maximum aperture setting, supply the next three f-numbers that would allow the irradiance to be reduced to $\frac{1}{3}$ the preceding at each successive stop.

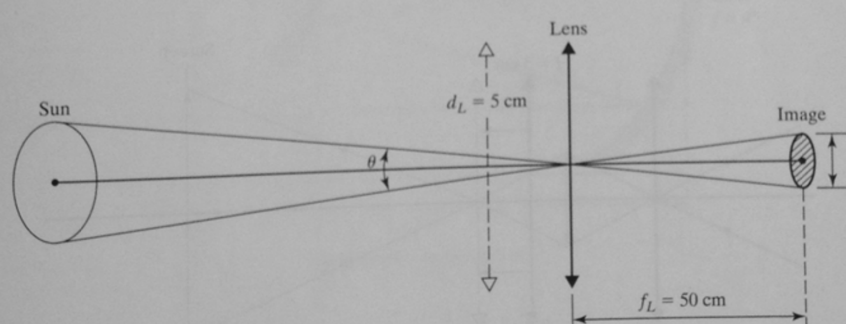

Figure 3-38 Problem 3-18.

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c. What aperture diameters correspond to these *f*-numbers?

d. If a picture is taken at maximum aperture and at $\frac{1}{100}$ s, what exposure time at each of the other openings provides equivalent total exposures?

3-21 The magnification given by Eq. (3-33) is also valid for a double-lens eyepiece if the equivalent focal length given by Eq. (3-35) is used. Show that the magnification of a double-lens eyepiece, designed to satisfy the condition for the elimination of chromatic aberration, is, for an image at infinity,

$$M = 12.5\left(\frac{1}{f_1} + \frac{1}{f_2}\right)$$

3-22 A magnifier is made of two thin plano-convex lenses, each of 3-cm focal length and spaced 2.8 cm apart. Find (a) the equivalent focal length and (b) the magnifying power for an image formed at the near point of the eye.

3-23 The objective of a microscope has a focal length of 0.5 cm and forms the intermediate image 16 cm from its second focal point.

a. What is the overall magnification of the microscope when an eyepiece rated at 10× is used?

b. At what distance from the objective is a point object viewed by the microscope?

3-24 A homemade compound microscope has, as objective and eyepiece, thin lenses of focal lengths 1 cm and 3 cm, respectively. An object is situated at a distance of 1.20 cm from the objective. If the virtual image produced by the eyepiece is 25 cm from the eye, compute (a) the magnifying power of the microscope and (b) the separation of the lenses.

3-25 Two thin convex lenses, when placed 25 cm apart, form a compound microscope whose apparent magnification is 20. If the focal length of the lens representing the eyepiece is 4 cm, determine the focal length of the other.

3-26 A level telescope contains a *graticule*—a circular glass on which a scale has been etched—in the common focal plane of objective and eyepiece so that it is seen in focus with a distant object. If the telescope is focused on a telephone pole 30 m away, how much of the post falls between millimeter marks on the graticule? The focal length of the objective is 20 cm.

3-27 A pair of binoculars is marked "7 × 35." The focal length of the objective is 14 cm, and the diameter of the field lens of the eyepiece is 1.8 cm. Determine (a) the angular magnification of a distant object, (b) the focal length of the ocular, (c) the diameter of the exit pupil, (d) the eye relief, and (e) the field of view in terms of feet at 1000 yd.

3-28 a. Show that when the final image is not viewed at infinity, the angular magnification of an astronomical telescope may be expressed by

$$M = -\frac{m_{oc} f_{obj}}{s''}$$

where m_{oc} is the linear magnification of the ocular and s'' is the distance from the ocular to the final image.

b. For such a telescope using two converging lenses with focal lengths of 30 cm and 4 cm, find the angular magnification when the image is viewed at infinity and when the image is viewed at a near point of 25 cm.

3-29 The moon subtends an angle of 0.5° at the objective lens of an astronomical telescope. The focal lengths of the objective and ocular lenses are 20 cm and 5 cm, respectively. Find the diameter of the image of the moon viewed through the telescope at near point of 25 cm.

3-30 An opera glass uses an objective and eyepiece with focal lengths of +12 cm and −4.0 cm, respectively. Determine the length (lens separation) of the instrument and its magnifying power for a viewer whose eyes are focused (a) for infinity and (b) for a near point of 30 cm.

3-31 An astronomical telescope is used to project a real image of the moon onto a screen 25 cm from an ocular of 5-cm focal length. How far must the ocular be moved from its normal position?

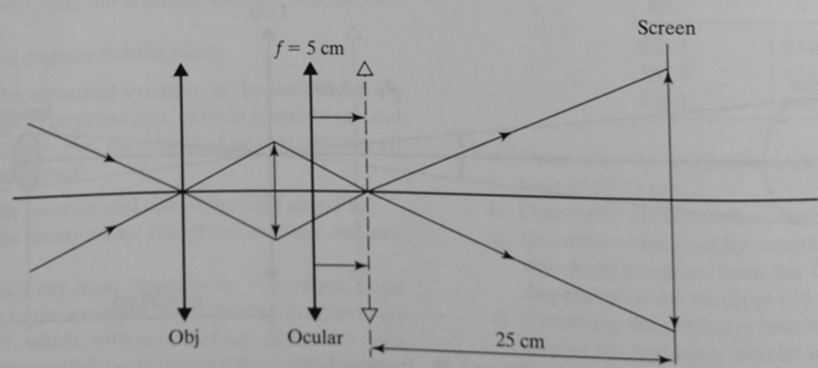

Figure 3-39 Problem 3-31.