

25

Optical Instruments

QUICK QUIZZES

1. (c). The corrective lens for a farsighted eye is a converging lens, while that for a nearsighted eye is a diverging lens. Since a converging lens is required to form a real image of the Sun on the paper to start a fire, the campers should use the glasses of the farsighted person.
2. (a). We would like to reduce the minimum angular separation for two objects below the angle subtended by the two stars in the binary system. We can do that by reducing the wavelength of the light — this in essence makes the aperture larger, relative to the light wavelength, increasing the resolving power. Thus, we would choose a blue filter.

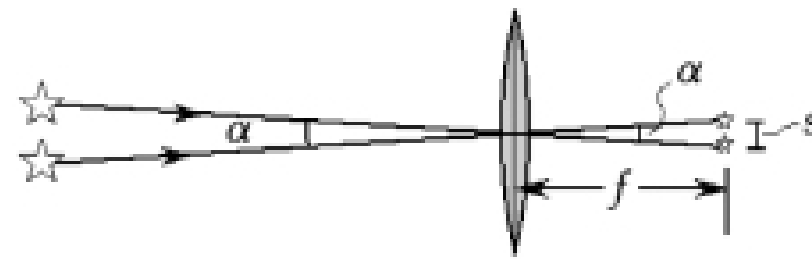
ANSWERS TO MULTIPLE CHOICE QUESTIONS

1. Diffraction of light as it passes through, or reflects from, the objective element of a telescope can cause the images of two sources having a small angular separation to overlap and fail to be seen as separate images. The minimum angular separation two sources must have in order to be seen as separate sources is inversely proportional to the diameter of the objective element. Thus, using a large diameter objective element in a telescope increases its resolution, making (c) the correct choice.
2. The power of a lens in diopters equals the reciprocal of the focal length when that focal length is expressed in meters. Hence, the power of a lens having a focal length of 25 cm is
$$P = \frac{1}{f} = \frac{1}{0.25 \text{ m}} = 4.0 \text{ diopters}$$
and choice (b) is the correct answer.
3. The amount of light focused on the film by a camera is proportional to the area of the aperture through which the light enters the camera. Since the area of a circular opening varies as the square of the diameter of the opening, the light reaching the film is proportional to the square of the diameter of the aperture. Thus, increasing this diameter by a factor of 3 increases the amount of light by a factor of 9, and (c) is the correct choice.
4. When the eye is shorter than normal, the lens-cornea system fails to bring light from near objects to a focus by the time it reaches the retina, resulting in a blurry image. Light rays entering the pupil from distant objects are less divergent than those from near objects, and the lens-cornea system can focus them on the retina. Such an eye is farsighted, or has hyperopia, and needs a converging corrective lens to help bring rays from near objects to focus sooner. The correct choice is (c).
5. When the eye is longer than normal, the lens-cornea system will bring light from distant objects to focus before it reaches the retina. Rays from near objects are more divergent and the lens-cornea system brings them to focus farther from the lens, on the retina. This means that the eye can see near objects clearly, but is unable to focus on distant objects. Such an eye is nearsighted (myopia), and needs a diverging corrective lens to make the rays from distant objects more divergent before they enter the eye. Choice (b) is the correct answer.

6. Stars are very distant and the reciprocal of the object distance in the lens or mirror equation

$$1/p + 1/q = 1/f$$

is essentially zero. This means that $q = f$, or the images are formed at a distance equal to the focal length from the objective element. Thus, the angular separation of the images, and hence the stars, is



$$\alpha = \frac{s}{f} = \frac{20.0 \times 10^{-3} \text{ m}}{2.00 \text{ m}} = 1.00 \times 10^{-2} \text{ rad} \left(\frac{360^\circ}{2\pi \text{ rad}} \right) = 0.573^\circ$$

and we see that choice (d) is the correct answer.

7. The corrective lens must form an upright, virtual image located 55 cm in front of the lens ($q = -55 \text{ cm}$) when the object is 25 cm in front of the lens ($p = +25 \text{ cm}$). The thin lens equation then gives the required focal length as

$$f = \frac{pq}{p+q} = \frac{(25 \text{ cm})(-55 \text{ cm})}{25 \text{ cm} - 55 \text{ cm}} = +46 \text{ cm}$$

and the correct choice is (c).

8. When a compound microscope is adjusted for most relaxed viewing (i.e., the final image formed by the eyepiece is at infinity), the approximate overall magnification produced by the microscope is given by the expression

$$m = -\frac{L}{f_o} \left(\frac{25 \text{ cm}}{f_e} \right)$$

where L is the length of the microscope, f_o is the focal length of the objective lens, and f_e is the focal length of the eyepiece. With the microscope described, the approximate magnification is

$$m = -\frac{15 \text{ cm}}{4.0 \text{ cm}} \left(\frac{25 \text{ cm}}{0.80 \text{ cm}} \right) = -1.2 \times 10^2 \quad \text{or} \quad |m| = 120$$

and the correct answer is choice (d).

9. The angular separation of the two stars is $\theta = s/r = (10^{-5} \text{ ly})/(200 \text{ ly}) = 5 \times 10^{-8}$ radians. The limiting angle of resolution for a circular aperture is $\theta_{\min} = 1.22(\lambda/D)$. Requiring that $\theta_{\min} = \theta$, and assuming a wavelength at the center of the visible spectrum (550 nm), the required diameter of the aperture is found to be

$$D = \frac{1.22\lambda}{\theta} = \frac{1.22(550 \times 10^{-9} \text{ m})}{5 \times 10^{-8} \text{ rad}} = 1 \times 10^1 \text{ m} = 10 \text{ m}$$

so (c) is the best choice of the listed possible answers.

10. When using light of wavelength λ , the resolving power needed to distinguish two closely spaced spectral lines having a difference in wavelength of $\Delta\lambda$ is $R = \lambda/\Delta\lambda$. Thus, if two lines in the visible spectrum differ in wavelength by $\Delta\lambda = 0.1 \text{ nm}$, the minimum resolving power of a diffraction grating that might be used to separate them is

$$R_{\min} = \frac{\lambda_{\min}}{\Delta\lambda} = \frac{400 \text{ nm}}{0.1 \text{ nm}} = 4 \times 10^3 = 4\,000$$

and the correct choice is (b).

ANSWERS TO CONCEPTUAL QUESTIONS

2. The objective lens of the microscope must form a real image just inside the focal point of the eyepiece lens. In order for this to occur, the object must be located just outside the focal point of the objective lens. Since the focal length of the objective lens is typically quite short (~ 1 cm), this means that the microscope can focus properly only on objects close to the end of the barrel and will be unable to focus on objects across the room.
4. For a lens to operate as a simple magnifier, the object should be located just inside the focal point of the lens. If the power of the lens is $+20.0$ diopters, its focal length is
- $$f = (1.00 \text{ m})/\mathcal{P} = (1.00 \text{ m})/+20.0 = 0.0500 \text{ m} = 5.00 \text{ cm}$$
- The object should be placed slightly less than 5.00 cm in front of the lens.
6. The aperture of a camera is a close approximation to the iris of the eye. The retina of the eye corresponds to the film of the camera, and a close approximation to the cornea of the eye is the lens of the camera.
8. You want a real image formed at the location of the paper. To form such an image, the object distance must be greater than the focal length of the lens.
10. Under low ambient light conditions, a photoflash unit is used to insure that light entering the camera lens will deliver sufficient energy for a proper exposure to each area of the film. Thus, the most important criterion is the additional energy per unit area (product of intensity and the duration of the flash, assuming this duration is less than the shutter speed) provided by the flash unit.
12. The angular magnification produced by a simple magnifier is $m = (25 \text{ cm})/f$. Note that this is proportional to the optical power of a lens, $\mathcal{P} = 1/f$, where the focal length f is expressed in meters. Thus, if the power of the lens is doubled, the angular magnification will also double.

PROBLEM SOLUTIONS

- 25.1 The f -number (or focal ratio) of a lens is defined to be the ratio of focal length of the lens to its diameter. Therefore, the f -number of the given lens is

$$f\text{-number} = \frac{f}{D} = \frac{28 \text{ cm}}{4.0 \text{ cm}} = \boxed{7.0}$$

- 25.2 If a camera has a lens with focal length of 55 mm and can operate at f -numbers that range from $f/1.2$ to $f/22$, the aperture diameters for the camera must range from

$$D_{\min} = \frac{f}{(f\text{-number})_{\max}} = \frac{55 \text{ mm}}{22} = \boxed{2.5 \text{ mm}}$$

to

$$D_{\max} = \frac{f}{(f\text{-number})_{\min}} = \frac{55 \text{ mm}}{1.2} = \boxed{46 \text{ mm}}$$