CHAPTER 33: Lenses and Optical Instruments

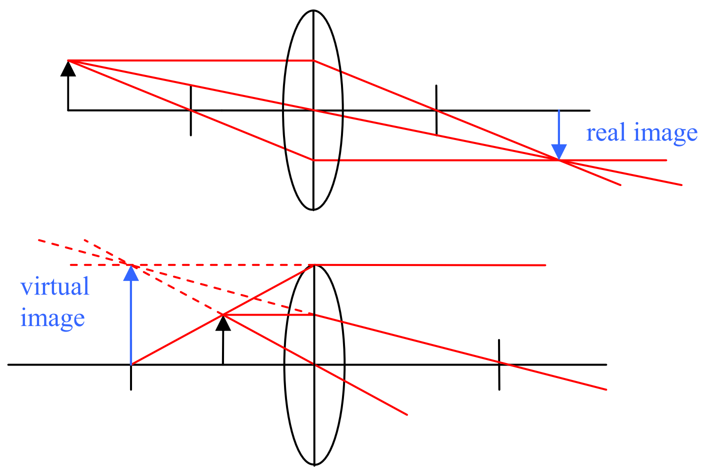
Responses to Questions

1. The film must be placed behind the lens at the focal length of the lens.

2. The lens moves farther away from the film. When the photographer moves closer to his subject, the object distance decreases. The focal length of the lens does not change, so the image distance must increase, by Eq. 33-2, $\frac{1}{f}=\frac{1}{d_o}+\frac{1}{d_i}$.

3. Yes. Diverging lenses, by definition, cause light rays to diverge and will not bring rays from a real object to a focal point as required to form a real image. However, if another optical element (for example, a converging lens) forms a virtual object for the diverging lens, it is possible for the diverging lens to form a real image.

4. A real image formed by a thin lens is on the opposite side of the lens as the object, and will always be inverted as shown in the top diagram. A virtual image is formed on the same side of the lens as the real object, and will be upright, as shown in the bottom diagram.



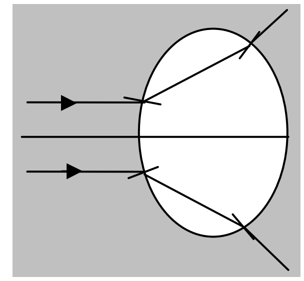
5. Yes. In the thin-lens equation, the variables for object distance and image distance can be interchanged and the formula remains the same.

6. Yes, real images can be projected on a screen. No, virtual images cannot, because they are formed by diverging rays, which do not come to a focus on the screen. Both kinds of images can be photographed. The lenses in a camera are designed to focus either converging or diverging light rays down onto the film.

7. (*a*) Yes. The image moves farther from the lens.
   (*b*) Yes. The image also gets larger.

8. The mirror equation and the lens equation are identical. According to the sign conventions, $d > 0$ indicates a real object or image and $d < 0$ indicates a virtual object or image, for both mirrors and lenses. But the positions of the objects and images are different for a mirror and a lens. For a mirror, a real object or image will be in front of the mirror and a virtual object or image will be behind the mirror. For a lens, a real image will be on the opposite side of the lens from a real object, and a virtual image will be on the same side of the lens as the real object.

9. No. The lens will be a diverging lens when placed in water because the index of refraction of the lens is less than the index of refraction of the medium surrounding it. Rays going from water to lens material will bend away from the normal instead of toward the normal, and rays going from the lens back to the water will bend towards the normal.



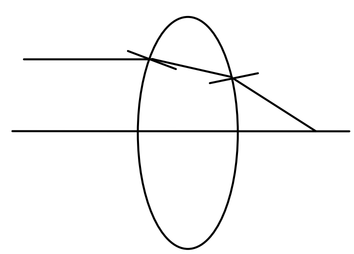
10. A virtual image created by a previous lens can serve as a virtual object for a second lens. If the previous lens creates an image behind the position of the second lens, that image will also serve as a virtual object for the second lens.

11. Assuming that the lens remains fixed and the screen is moved, the dog's head will have the greater magnification. The object distance for the head is less than the object distance for the tail, because the dog is facing the mirror. The image distance for the head will therefore be greater than the image distance for the tail. Magnification is the ratio of the image distance to the object distance, so will be greater for the head.

12. If the cat's nose is closer to the lens than the focal point and the tail is farther from the lens than the focal point, the image of the nose will be virtual and the image of the tail will be real. The virtual image of the front part of the cat will be spread out from the image of the nose to infinity on the same side of the lens as the cat. The real image of the back part of the cat will be spread out from the image of the tail to infinity on the opposite side of the lens.

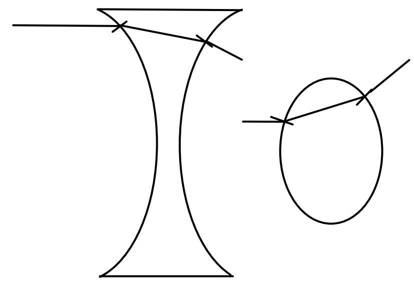
13. The technique for determining the focal length of the diverging lens in Example 33-6 requires the combination of the two lenses together to project a real image of the sun onto a screen. The focal length of the lens combination can be measured. If the focal length of the converging lens is longer than the focal length of the diverging lens (the converging lens is weaker than the diverging lens), then the lens combination will be diverging, and will not form a real image of the sun. In this case the focal length of the combination of lenses cannot be measured, and the focal length of the diverging lens alone cannot be determined.

14. A double convex lens causes light rays to converge because the light bends towards the normal as it enters the lens and away from the normal as it exits the lens. The result, due to the curvature of the sides of the lens, is that the light bends towards the principal axis at both surfaces. The more strongly the sides of the lens are curved, the greater the bending, and the shorter the focal length.



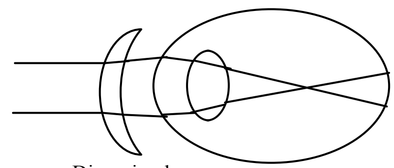
15. Yes. The relative values of the index of refraction of the fluid and the index of refraction of the lens will determine the refraction of light as it passes from the fluid through the lens and back into the fluid. The amount of refraction of light determines the focal length of the lens, so the focal length will change if the lens is immersed in a fluid. No, the image formation of the spherical mirror is determined by reflection, not refraction, and is independent of the medium in which the mirror is immersed.

16. The lens material is air and the medium in which the lens is placed is water. Air has a lower index of refraction than water, so the light rays will bend away from the normal when entering the lens and towards the normal when leaving the lens.
    (*a*) A converging lens can be made by a shape that is thinner in the middle than it is at the edges.
    (*b*) A diverging lens will be thicker in the middle than it is at the edges.



17. If the object of the second lens (the image from the first lens) is exactly at the focal point, then a virtual image will be formed at infinity and can be viewed with a relaxed eye.

18. The corrective lenses will not work the same underwater as in air, and so the nearsighted person will probably not be able to see clearly underwater. The difference in the index of refraction of water and glass is much smaller than the difference in the indices for air and glass, so the lenses will not cause the incoming rays to diverge sufficiently.



19. Nearsighted. Diverging lenses are used to correct nearsightedness and converging lenses are used to correct farsightedness. If the person's face appears narrower through the glasses, then the image of the face produced by the lenses is smaller than the face, virtual, and upright. Thus, the lenses must be diverging, and therefore the person is nearsighted.

20. All light entering the camera lens while the shutter is open contributes to a single picture. If the camera is moved while the shutter is open, the position of the image on the film moves. The new image position overlaps the previous image position, causing a blurry final image. With the eye, new images are continuously being formed by the nervous system, so images do not "build up" on the retina and overlap with each other.

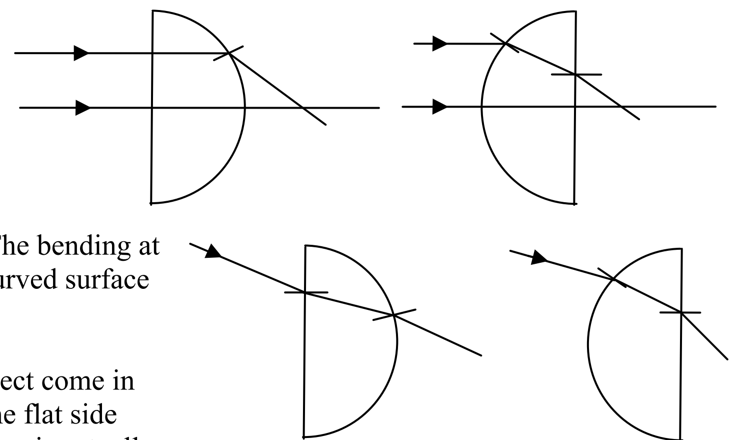
21. Squinting limits the off-axis rays that enter the eye and results in an image that is formed primarily by the center part of the lens, reducing spherical aberration and spreading of the image.

22. The image formed on the retina is inverted. The human brain then processes the image so that we interpret the world we see correctly.

23. Both reading glasses and magnifiers are converging lenses used to produce magnified images. A magnifier, generally a short focal length lens, is typically used by adjusting the distance between the lens and the object so that the object is exactly at or just inside the focal point. An object exactly at the focal point results in an image that is at infinity and can be viewed with a relaxed eye. If the lens is adjusted so that it focuses the image at the eye's near point, the magnification is slightly greater. The lenses in reading glasses typically are a fixed distance from the eye. These lenses cause the rays from a nearby object to converge somewhat before they reach the eye, allowing the eye to focus on an object that is inside the near point. The focal length of the lens needed for reading glasses will depend on the individual eye. The object does not have to be inside the focal point of the lens. For both reading glasses and magnifiers, the lenses allow the eye to focus on an object closer than the near point.

24. The relationship between d_i and d_o for a given lens of focal length f is given by Eq. 33-2, $\frac{1}{d_o}+\frac{1}{d_i}=\frac{1}{f}$. The focal length is fixed for a camera lens, so if the lens focuses on a closer object, d_o decreases and therefore d_i must increase. An increase in d_i means that the lens must be farther from the film.

25. The curved surface should face the object. If the flat surface faces the object and the rays come in parallel to the optical axis, then no bending will occur at the first surface and all the bending will occur at the second surface. Bending at the two surfaces will clearly not be equal in this case. The bending at the two surfaces may be equal if the curved surface faces the object.

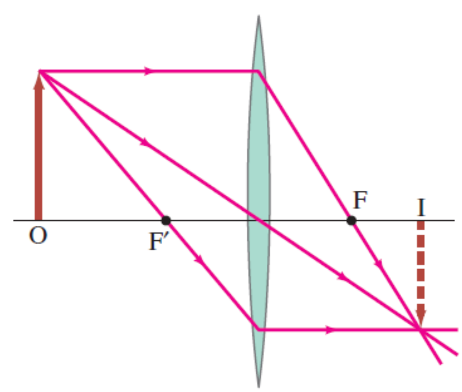


If the parallel rays from the distant object come in above or below the optical axis with the flat side towards the object, then the first bending is actually away from the axis. In this case also, bending at both surfaces can be equal if the curved side of the lens faces the object.

26. For both converging and diverging lenses, the focal point for violet light is closer to the lens than the focal point for red light. The index of refraction for violet light is slightly greater than for red light for glass, so the violet light bends more, resulting in a smaller magnitude focal length.

Solutions to Problems

1. (*a*) From the ray diagram, the object distance is about $\boxed{480\text{ cm}}$.



(*b*) We find the object distance from Eq. 33-2.

$$\frac{1}{d_o}+\frac{1}{d_i}=\frac{1}{f} \quad \rightarrow$$

$$d_o=\frac{fd_i}{d_i-f}=\frac{(215\,\text{mm})(373\,\text{mm})}{373\,\text{mm}-215\,\text{mm}}=\boxed{508\,\text{mm}}$$

NOTE: In the first printing of the textbook, a different set of values was given: $f=75.0\,\text{mm}$ and $d_i=88.0\,\text{mm}$. Using that set of values gives the same object distance as above. But the ray diagram would be much more elongated, with the object distance almost 7 times the focal length.

2. (*a*) To form a real image from parallel rays requires a $\boxed{\text{converging lens.}}$

(*b*) We find the power of the lens from Eqs. 33-1 and 33-2.

$$\frac{1}{d_o}+\frac{1}{d_i}=\frac{1}{f}=P=\frac{1}{\infty}+\frac{1}{0.185\,\text{m}}=\boxed{5.41\,\text{D}}$$

3. (*a*) The power of the lens is given by Eq. 33.1

$$P=\frac{1}{f}=\frac{1}{0.235\,\text{m}}=\boxed{4.26\,\text{D}}$$

This lens is $\boxed{\text{converging}}$.

(*b*) We find the focal length of the lens from Eq. 33.1

$$P=\frac{1}{f}\;\rightarrow\; f=\frac{1}{D}=-\frac{1}{6.75\,\text{D}}=\boxed{-0.148\,\text{m}}$$

This lens is $\boxed{\text{diverging}}$.

4. To form a real image from a real object requires a $\boxed{\text{converging lens}}$. We find the focal length of the lens from Eq. 33-2.

$$\frac{1}{d_o}+\frac{1}{d_i}=\frac{1}{f}\;\rightarrow\; f=\frac{d_od_i}{d_o+d_i}=\frac{(1.85\,\text{m})(0.483\,\text{m})}{1.85\,\text{m}+0.483\,\text{m}}=\boxed{0.383\,\text{m}}$$

Because $d_i>0$, the image is $\boxed{\text{real.}}$

5. (*a*) We find the image distance from Eq. 33-2.

$$\frac{1}{d_o}+\frac{1}{d_i}=\frac{1}{f}\;\rightarrow\; d_i=\frac{d_of}{d_o-f}=\frac{(10.0\,\text{m})(0.105\,\text{m})}{10.0\,\text{m}-0.105\,\text{m}}=0.106\,\text{m}=\boxed{106\,\text{mm}}$$

(*b*) Use the same general calculation.

$$d_i=\frac{d_of}{d_o-f}=\frac{(3.0\,\text{m})(0.105\,\text{m})}{3.0\,\text{m}-0.105\,\text{m}}=0.109\,\text{m}=\boxed{109\,\text{mm}}$$

(*c*) Use the same general calculation.

$$d_i=\frac{d_of}{d_o-f}=\frac{(1.0\,\text{m})(0.105\,\text{m})}{1.0\,\text{m}-0.105\,\text{m}}=0.117\,\text{m}=\boxed{117\,\text{mm}}$$

(*d*) We find the smallest object distance from the maximum image distance.

$$\frac{1}{d_{o_{min}}}+\frac{1}{d_{i_{max}}}=\frac{1}{f}\;\rightarrow\; d_{o_{min}}=\frac{d_{i_{max}}-f}{d_{i_{max}}\,f}=\frac{(132\,\text{mm})(105\,\text{mm})}{132\,\text{mm}-105\,\text{mm}}=513\,\text{mm}=\boxed{0.513\,\text{m}}$$

6. (*a*) We locate the image using Eq. 33-2.

$$\frac{1}{d_o}+\frac{1}{d_i}=\frac{1}{f}\;\rightarrow\; d_i=\frac{d_of}{d_o-f}=\frac{(18\,\text{cm})(28\,\text{cm})}{18\,\text{cm}-28\,\text{cm}}=-50.4\,\text{cm}\approx-50\,\text{cm}$$

The negative sign means the image is $\boxed{\text{50 cm behind the lens (virtual).}}$

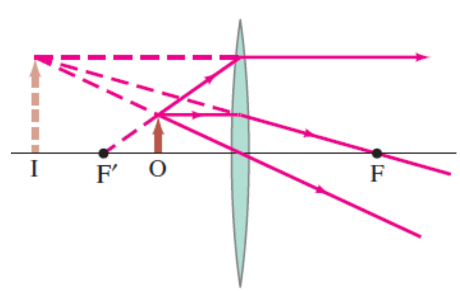
(*b*) We find the magnification from Eq. 33-3.

$$m=-\frac{d_i}{d_o}=-\frac{(-50.4\,\text{cm})}{(18\,\text{cm})}=\boxed{+2.8}$$

$\boxed{7.}$ (*a*) The image should be upright for reading. The image will be $\boxed{\text{virtual, upright, and magnified}}$.

(*b*) To form a virtual, upright magnified image requires a $\boxed{\text{converging lens}}$.

(*c*) We find the image distance, then the focal length, and then the power of the lens. The object distance is given.



$$m=-\frac{d_i}{d_o} \rightarrow d_i=-md_o$$

$$P=\frac{1}{f}=\frac{1}{d_o}+\frac{1}{d_i}=\frac{d_i+d_o}{d_od_i}=\frac{-md_o+d_o}{d_o(-md_o)}=\frac{m-1}{md_o}=\frac{2.5-1}{(2.5)(0.090\,\text{m})}=\boxed{6.7\,\text{D}}$$

8. Use Eqs. 33-1 and 33-2 to find the image distance, and Eq. 33-3 to find the image height.

$$\frac{1}{d_o}+\frac{1}{d_i}=\frac{1}{f}=P \rightarrow d_i=\frac{d_o}{Pd_o-1}=\frac{(0.125\,\text{m})}{(-8.00\,\text{D})(0.125\,\text{m})-1}=-0.0625\,\text{m}=\boxed{-6.25\,\text{cm}}$$

Since the image distance is negative, the image is $\boxed{\text{virtual and behind the lens}}$.

$$m=\frac{h_i}{h_o}=-\frac{d_i}{d_o} \rightarrow h_i=-\frac{d_i}{d_o}h_o=-\frac{(-6.25\,\text{cm})}{12.5\,\text{cm}}(1.00\,\text{mm})=\boxed{0.500\,\text{mm}\,(\text{upright})}$$

9. First, find the original image distance from Eqs. 33-1 and 33-2.

$$\frac{1}{d_o}+\frac{1}{d_i}=\frac{1}{f}=P \rightarrow d_i=\frac{d_o}{Pd_o-1}=\frac{(1.50\,\text{m})}{(8.00\,\text{D})(1.50\,\text{m})-1}=0.1364\,\text{m}$$

(*a*) With $d_o=0.60\,\text{m}$, find the new image distance.

$$\frac{1}{d_o}+\frac{1}{d_i}=\frac{1}{f}=P \rightarrow d_i=\frac{d_o}{Pd_o-1}=\frac{(0.60\,\text{m})}{(8.00\,\text{D})(0.60\,\text{m})-1}=0.1579\,\text{m}$$

Thus the image has moved $0.1579\,\text{m}-0.1364\,\text{m}=0.0215\,\text{m}\approx\boxed{0.02\,\text{m}}$ away from the lens.

(*b*) With $d_o=2.40\,\text{m}$, find the new image distance.

$$\frac{1}{d_o}+\frac{1}{d_i}=\frac{1}{f}=P \rightarrow d_i=\frac{d_o}{Pd_o-1}=\frac{(2.40\,\text{m})}{(8.00\,\text{D})(2.40\,\text{m})-1}=0.1319\,\text{m}$$

The image has moved $0.1319\,\text{m}-0.1364\,\text{m}=-0.0045\,\text{m}\approx\boxed{0.004\,\text{m}}$ toward the lens.

10. (*a*) If the image is real, the focal length must be positive, the image distance must be positive, and the magnification is negative. Thus $d_i=2.50d_o$. Use Eq. 33-2.

$$\frac{1}{d_o}+\frac{1}{d_i}=\frac{1}{d_o}+\frac{1}{2.50d_o}=\frac{1}{f} \rightarrow d_o=\left(\frac{3.50}{2.50}\right)f=\left(\frac{3.50}{2.50}\right)(50.0\,\text{mm})=\boxed{70.0\,\text{mm}}$$

(*b*) If the image is magnified, the lens must have a positive focal length, because negative lenses always form reduced images. Since the image is virtual the magnification is positive. Thus $d_i=-2.50d_o$. Again use Eq. 33-2.

$$\frac{1}{d_o}+\frac{1}{d_i}=\frac{1}{d_o}-\frac{1}{2.5d_o}=\frac{1}{f} \rightarrow d_o=\left(\frac{1.50}{2.50}\right)f=\left(\frac{1.50}{2.50}\right)(50.0\,\text{mm})=\boxed{30.0\,\text{mm}}$$

11. From Eq. 33-3, $|h_i|=|h_o|$ when $d_i=d_o$. So find d_o from Eq. 33-2.

$$\frac{1}{d_o}+\frac{1}{d_i}=\frac{1}{d_o}+\frac{1}{d_o}=\frac{1}{f} \rightarrow d_o=2f=\boxed{50\,\text{cm}}$$

12. (*a*) Use Eqs. 33-2 and 33-3.

$$\frac{1}{d_o}+\frac{1}{d_i}=\frac{1}{f} \rightarrow d_i=\frac{d_of}{d_o-f}=\frac{(1.30\,\text{m})(0.135\,\text{m})}{1.30\,\text{m}-0.135\,\text{m}}=0.1506\,\text{m}\approx\boxed{151\,\text{mm}}$$

$$m = \frac{h_i}{h_o} = -\frac{d_i}{d_o} \rightarrow h_i = -\frac{d_i}{d_o}h_o = -\frac{0.1506\,\text{m}}{1.30\,\text{m}}(2.80\,\text{cm}) = \boxed{-0.324\,\text{m}}$$

The image is behind the lens a distance of 151 mm, is real, and is inverted.

(*b*) Again use Eqs. 33-2 and 33-3.

$$\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f} \rightarrow d_i = \frac{d_o f}{d_o - f} = \frac{(1.30\,\text{m})(-0.135\,\text{m})}{1.30\,\text{m} - (-0.135\,\text{m})} = -0.1223\,\text{m} \approx \boxed{-122\,\text{mm}}$$

$$m = \frac{h_i}{h_o} = -\frac{d_i}{d_o} \rightarrow h_i = -\frac{d_i}{d_o}h_o = -\frac{(-0.1223\,\text{m})}{1.30\,\text{m}}(2.80\,\text{cm}) = \boxed{0.263\,\text{m}}$$

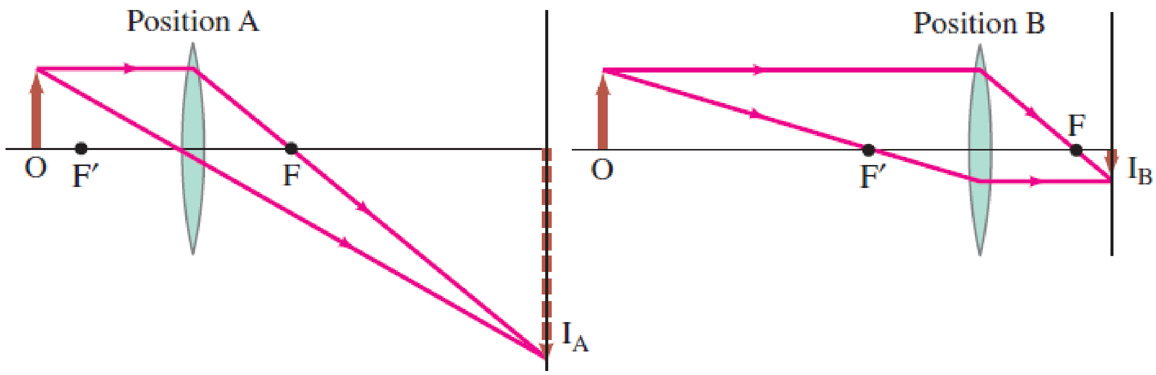
The image is in front of the lens a distance of 122 mm, is virtual, and is upright.

13. The sum of the object and image distances must be the distance between object and screen, which we label as d_T. We solve this relationship for the image distance, and use that expression in Eq. 33-2 in order to find the object distance.

$$d_o + d_i = d_T \rightarrow d_i = d_T - d_o \;;\; \frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{d_o} + \frac{1}{(d_T - d_o)} = \frac{1}{f} \rightarrow d_o^2 - d_T d_o + f d_T = 0 \rightarrow$$

$$d_o = \frac{d_T \pm \sqrt{d_T^2 - 4fd_T}}{2} = \frac{(86.0\,\text{cm}) \pm \sqrt{(86.0\,\text{cm})^2 - 4(16.0\,\text{cm})(86.0\,\text{cm})}}{2} = \boxed{21.3\,\text{cm},\ 64.7\,\text{cm}}$$

Note that to have real values for d_o, we must in general have $d_T^2 - 4fd_T > 0 \rightarrow d_T > 4f$.



14. For a real image both the object distance and image distances are positive, and so the magnification is negative. Use Eqs. 33-2 and 33-3 to find the object and image distances. Since they are on opposite sides of the lens, the distance between them is their sum.

$$m = \frac{-d_i}{d_o} \rightarrow d_i = -md_o = 2.95d_o$$

$$\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{d_o} + \frac{1}{2.95d_o} = \frac{1}{f} \rightarrow d_o = \left(\frac{3.95}{2.95}\right)f = \left(\frac{3.95}{2.95}\right)(85\,\text{cm}) = 113.8\,\text{cm}$$

$$d_i = 2.95d_o = 2.95(113.8\,\text{cm}) = 335.7\,\text{cm}$$

$$d_o + d_i = 113.8\,\text{cm} + 335.7\,\text{cm} = 449.5\,\text{cm} \approx \boxed{450\,\text{cm}}$$

15. (*a*) Use Eq. 33-2 to write an expression for the image distance in terms of the object distance and focal length. We then use Eq. 33-3 to write an expression for the magnification.

$$\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f} \rightarrow d_i = \frac{d_o f}{d_o - f} \;;\; m = -\frac{d_i}{d_o} = -\frac{f}{d_o - f}$$

These expressions show that when $d_o > f$, the image distance is positive, producing a real image, and the magnification is negative, which gives an inverted image.

(*b*) From the above equations, when $d_o < f$, the image distance is negative, producing a virtual image, and the magnification is positive, which gives an upright image.

(*c*) We set $-d_o = f$ and calculate the limiting image distance and magnification.

$$d_i = \frac{(-f)f}{-f-f} = \frac{f}{2} \qquad m = -\frac{d_i}{d_o} = -\frac{f}{-f-f} = \frac{1}{2}$$

We also take the limit of large negative object distance.

$$d_i = \frac{(-\infty)f}{-\infty - f} = f \qquad m = -\frac{d_i}{d_o} = -\frac{f}{-\infty - f} = 0$$

From these limiting cases, we see that when $-d_o > f$, the image is $\boxed{\text{real and upright}}$ with $\frac{1}{2}f < d_i < f$ and $0 < m < \frac{1}{2}$.

(*d*) We take the limiting condition $d_o \to 0$, and determine the resulting image distance and magnification.

$$d_i = \frac{(0)f}{0-f} = 0 \qquad m = -\frac{d_i}{d_o} = -\frac{f}{0-f} = 1$$

From this limit and that found in part (*c*), we see that when $0 < -d_o < f$, the image is $\boxed{\text{real and upright}}$, with $0 < d_i < \frac{1}{2}f$ and $\frac{1}{2} < m < 1$.

16. (*a*) We use the magnification equation, Eq. 33-3, to write the image distance in terms of the magnification and object distance. We then replace the image distance in the mirror equation, Eq. 32-2, and solve for the magnification in terms of the object distance and the focal length.

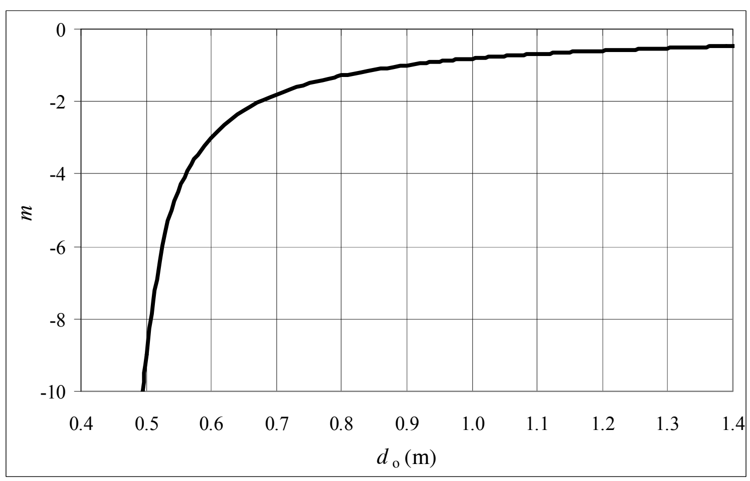
$$m = -d_i/d_o \quad \to \quad d_i = -md_o$$

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i} \quad \to$$

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{-md_o} \quad \to$$

$$\boxed{m = \frac{f}{f - d_o}}$$

(*b*) We set $f = 0.45\ \text{m}$ and draw a graph of the magnification as a function of the object distance. The spreadsheet used for this problem can be found on the Media Manager, with filename "PSE4_ISM_CH33.XLS," on tab "Problem 33.16b."



(*c*) The image and object will have the same lateral size when the magnification is equal to negative one. Setting the magnification equal to negative one, we solve the equation found in part (a) for the object distance.

$$m = \frac{f}{f - d_o} = -1 \quad \to \quad d_o = 2f = \boxed{0.90\,\text{m}}$$

(*d*) From the graph we see that for the image to be much larger than the object, the object should be placed at a point $\boxed{\text{just beyond the focal point.}}$

17. Find the object distance from Eq. 33-2.

$$\frac{1}{d_o}+\frac{1}{d_i}=\frac{1}{f} \rightarrow \frac{1}{d_o}+\frac{1}{d_i}=\frac{1}{f} \rightarrow d_o=\frac{fd_i}{d_i-f}=\frac{(0.105\,\text{m})(6.50\,\text{m})}{6.50\,\text{m}-0.105\,\text{m}}=\boxed{0.107\,\text{m}}$$

Find the size of the image from Eq. 33-3.

$$m=\frac{h_i}{h_o}=-\frac{d_i}{d_o} \rightarrow |h_i|=\frac{d_i}{d_o}h_o=\frac{6.50\,\text{m}}{0.107\,\text{m}}(36\,\text{mm})=2187\,\text{mm}\approx\boxed{2.2\,\text{m}}$$

18. (*a*) Use Eq. 33-2 with $d_o+d_i=d_T \rightarrow d_i=d_T-d_o$.

$$\frac{1}{d_o}+\frac{1}{d_i}=\frac{1}{d_o}+\frac{1}{(d_T-d_o)}=\frac{1}{f} \rightarrow d_o^2-d_Td_o+fd_T=0 \rightarrow d_o=\frac{d_T\pm\sqrt{d_T^2-4fd_T}}{2}$$

There are only real solutions for d_o if $d_T^2-4fd_T>0 \rightarrow d_T>4f$. If that condition is met, then there will be two locations for the lens, at distances $d_o=\frac{1}{2}\left(d_T\pm\sqrt{d_T^2-4fd_T}\right)$ from the object, that will form sharp images on the screen.

(*b*) If $d_T<4f$, then Eq. 33-2 cannot be solved for real values of d_o or d_i.

(*c*) If $d_T>4f$, the lens locations relative to the object are given by $d_{o1}=\frac{1}{2}\left(d_T+\sqrt{d_T^2-4fd_T}\right)$ and $d_{o2}=\frac{1}{2}\left(d_T-\sqrt{d_T^2-4fd_T}\right)$.

$$\Delta d=d_{o1}-d_{o2}=\frac{1}{2}\left(d_T+\sqrt{d_T^2-4fd_T}\right)-\frac{1}{2}\left(d_T-\sqrt{d_T^2-4fd_T}\right)=\boxed{\sqrt{d_T^2-4fd_T}}$$

Find the ratio of image sizes using Eq. 33-3.

$$\frac{h_{i2}}{h_{i1}}=\frac{-h_o\frac{d_{i2}}{d_{o2}}}{-h_o\frac{d_{i1}}{d_{o1}}}=\frac{d_{i2}}{d_{o2}}\frac{d_{o1}}{d_{i1}}=\frac{d_T-d_{o2}}{d_{o2}}\frac{d_{o1}}{d_T-d_{o1}}$$

$$=\left[\frac{d_T-\frac{1}{2}\left(d_T-\sqrt{d_T^2-4fd_T}\right)}{\frac{1}{2}\left(d_T-\sqrt{d_T^2-4fd_T}\right)}\right]\left[\frac{\frac{1}{2}\left(d_T+\sqrt{d_T^2-4fd_T}\right)}{d_T-\frac{1}{2}\left(d_T+\sqrt{d_T^2-4fd_T}\right)}\right]=\boxed{\left(\frac{d_T+\sqrt{d_T^2-4fd_T}}{d_T-\sqrt{d_T^2-4fd_T}}\right)^2}$$

$\boxed{19.}$ (*a*) With the definitions as given in the problem, $x=d_o-f \rightarrow d_o=x+f$ and $x'=d_i-f \rightarrow d_i=x'+f$. Use Eq. 33-2.

$$\frac{1}{d_o}+\frac{1}{d_i}=\frac{1}{x+f}+\frac{1}{x'+f}=\frac{1}{f} \rightarrow \frac{(x'+f)+(x+f)}{(x+f)(x'+f)}=\frac{1}{f} \rightarrow$$

$$(2f+x+x')f=(x+f)(x'+f) \rightarrow 2f^2+xf+x'f=x'x+xf+fx'+f^2 \rightarrow \boxed{f^2=x'x}$$

(*b*) Use Eq. 33-2.

$$\frac{1}{d_o}+\frac{1}{d_i}=\frac{1}{f} \rightarrow d_i=\frac{d_of}{d_o-f}=\frac{(48.0\,\text{cm})(38.0\,\text{cm})}{48.0\,\text{cm}-38.0\,\text{cm}}=\boxed{182\,\text{cm}}$$

(*c*) Use the Newtonian form.

$$xx'=f^2 \rightarrow x'=\frac{f^2}{x}=\frac{(38.0\,\text{cm})^2}{(48.0\,\text{cm}-38.0\,\text{cm})}=144.2\,\text{cm}$$

$$d_i=x'+f=144.2\,\text{cm}+38.0\,\text{cm}=\boxed{182\,\text{cm}}$$

20. The first lens is the converging lens. An object at infinity will form an image at the focal point of the converging lens, by Eq. 33-2.

$$\frac{1}{d_{o1}}+\frac{1}{d_{i1}}=\frac{1}{f_1}=\frac{1}{\infty}+\frac{1}{d_{i1}} \quad \rightarrow \quad d_{i1}=f_1=20.0\,\text{cm}$$

This image is the object for the second lens. Since this image is behind the second lens, the object distance for the second lens is negative, and so $d_{o2}=-6.0\,\text{cm}$. Again use Eq. 33-2.

$$\frac{1}{d_{o2}}+\frac{1}{d_{i2}}=\frac{1}{f_2} \quad \rightarrow \quad d_{i2}=\frac{d_{o2}f_2}{d_{o2}-f_2}=\frac{(-6.0\,\text{cm})(-33.5\,\text{cm})}{(-6.0\,\text{cm})-(-33.5\,\text{cm})}=7.3\,\text{cm}$$

Thus the final image is real, 7.3 cm beyond the second lens.

21. Find the image formed by the first lens, using Eq. 33-2.

$$\frac{1}{d_{o1}}+\frac{1}{d_{i1}}=\frac{1}{f_1} \quad \rightarrow \quad d_{i1}=\frac{d_{o1}f_1}{d_{o1}-f_1}=\frac{(35.0\,\text{cm})(25.0\,\text{cm})}{(35.0\,\text{cm})-(25.0\,\text{cm})}=87.5\,\text{cm}$$

This image is the object for the second lens. Because it is beyond the second lens, it has a negative object distance.

$$d_{o2}=16.5\,\text{cm}-87.5\,\text{cm}=-71.0\,\text{cm}$$

Find the image formed by the second lens, again using Eq. 33-2.

$$\frac{1}{d_{o2}}+\frac{1}{d_{i2}}=\frac{1}{f_2} \quad \rightarrow \quad d_{i2}=\frac{d_{o2}f_2}{d_{o2}-f_2}=\frac{(-71.0\,\text{cm})(25.0\,\text{cm})}{(-71.0\,\text{cm})-(25.0\,\text{cm})}=18.5\,\text{cm}$$

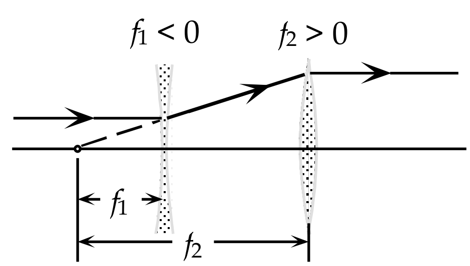
Thus the final image is real, 18.5 cm beyond second lens.

The total magnification is the product of the magnifications for the two lenses:

$$m=m_1m_2=\left(-\frac{d_{i1}}{d_{o1}}\right)\left(-\frac{d_{i2}}{d_{o2}}\right)=\frac{d_{i1}d_{i2}}{d_{o1}d_{o2}}$$

$$=\frac{(+87.5\,\text{cm})(+18.5\,\text{cm})}{(+35.0\,\text{cm})(-71.0\,\text{cm})}=\boxed{-0.651\times(\text{inverted})}$$

22. From the ray diagram, the image from the first lens is a virtual image at the focal point of the first lens. This is a real object for the second lens. Since the light is parallel after leaving the second lens, the object for the second lens must be at its focal point. Let the separation of the lenses be ℓ. Note that the focal length of the diverging lens is negative.



$$|f_1|+\ell=f_2 \quad \rightarrow$$

$$|f_1|=f_2-\ell=34.0\,\text{cm}-24.0\,\text{cm}=10.0\,\text{cm} \quad \rightarrow$$

$$f_1=\boxed{-10.0\,\text{cm}}$$

23. (*a*) The first image is formed as in Example 33-5, and so $d_{iA}=30.0\,\text{cm}$. This image becomes the object for the lens B, at a distance $d_{oB}=20.0\,\text{cm}-30.0\,\text{cm}=-10.0\,\text{cm}$. This is a virtual object since it is behind lens N. Use Eq. 33-2 to find the image formed by lens B, which is the final image.

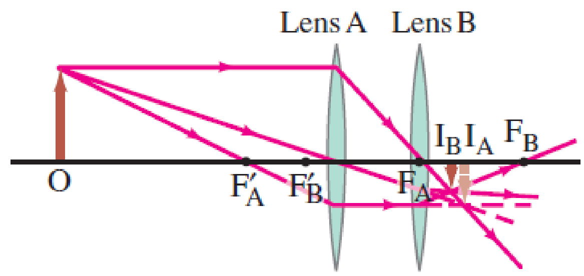
$$\frac{1}{d_{oB}}+\frac{1}{d_{iB}}=\frac{1}{f_B} \quad \rightarrow \quad d_{iB}=\frac{d_{oB}f_B}{d_{oB}-f_B}=\frac{(-10.0\,\text{cm})(25.0\,\text{cm})}{-10.0\,\text{cm}-25.0\,\text{cm}}=7.14\,\text{cm}$$

So the final image is 7.14 cm beyond lens B.

(*b*) The total magnification is the product of the magnifications for the two lenses:

$$m = m_1 m_2 = \left(-\frac{d_{iA}}{d_{oA}}\right)\left(-\frac{d_{iB}}{d_{oB}}\right) = \frac{d_{iA} d_{iB}}{d_{oA} d_{oB}} = \frac{(30.0\,\text{cm})(7.14\,\text{cm})}{(60.0\,\text{cm})(-10.0\,\text{cm})} = \boxed{-0.357}$$

(*c*) See the ray diagram here.



24\. (*a*) Find the image formed by the converging lens, using Eq. 33-2.

$$\frac{1}{d_{o1}} + \frac{1}{d_{i1}} = \frac{1}{f_1} \rightarrow d_{i1} = \frac{d_{o1} f_1}{d_{o1} - f_1} = \frac{(33\,\text{cm})(18\,\text{cm})}{(33\,\text{cm}) - (18\,\text{cm})} = 39.6\,\text{cm}$$

This image is the object for the second lens. The image is to the right of the second lens, and so is virtual. Use that image to find the final image.

$$d_{o2} = 12\,\text{cm} - 39.6\,\text{cm} = -27.6\,\text{cm} \;;\; \frac{1}{d_{o2}} + \frac{1}{d_{i2}} = \frac{1}{f_2} \rightarrow$$

$$d_{i2} = \frac{d_{o2} f_2}{d_{o2} - f_2} = \frac{(-27.6\,\text{cm})(-14\,\text{cm})}{(-27.6\,\text{cm}) - (-14\,\text{cm})} = -28.4\,\text{cm}$$

So the final image is 28 cm to the left of the diverging lens, or $\boxed{\text{16 cm to the left of the converging lens}}$.

(*b*) The initial image is unchanged. With the change in the distance between the lenses, the image distance for the second lens has changed.

$$d_{o2} = 38\,\text{cm} - 39.6\,\text{cm} = -1.6\,\text{cm} \;;\; \frac{1}{d_{o2}} + \frac{1}{d_{i2}} = \frac{1}{f_2} \rightarrow$$

$$d_{i2} = \frac{d_{o2} f_2}{d_{o2} - f_2} = \frac{(-1.6\,\text{cm})(-14\,\text{cm})}{(-1.6\,\text{cm}) - (-14\,\text{cm})} = 1.8\,\text{cm}$$

Now the final image is $\boxed{\text{1.8 cm to the right of the diverging lens.}}$

$\boxed{25.}$ (*a*) The first lens is the converging lens. Find the image formed by the first lens.

$$\frac{1}{d_{o1}} + \frac{1}{d_{i1}} = \frac{1}{f_1} \rightarrow d_{i1} = \frac{d_{o1} f_1}{d_{o1} - f_1} = \frac{(60.0\,\text{cm})(20.0\,\text{cm})}{(60.0\,\text{cm}) - (20.0\,\text{cm})} = 30.0\,\text{cm}$$

This image is the object for the second lens. Since this image is behind the second lens, the object distance for the second lens is negative, and so $d_{o2} = 25.0\,\text{cm} - 30.0\,\text{cm} = -5.0\,\text{cm}$. Use Eq. 33-2.

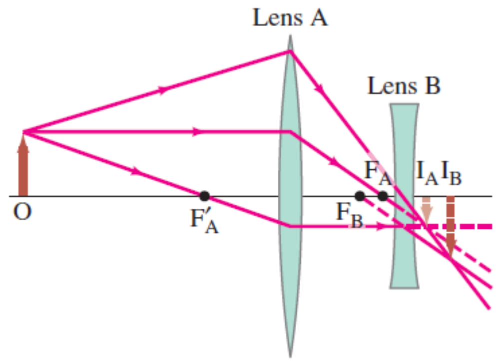
$$\frac{1}{d_{o2}} + \frac{1}{d_{i2}} = \frac{1}{f_2} \rightarrow d_{i2} = \frac{d_{o2} f_2}{d_{o2} - f_2} = \frac{(-5.0\,\text{cm})(-10.0\,\text{cm})}{(-5.0\,\text{cm}) - (-10.0\,\text{cm})} = 10\,\text{cm}$$

Thus the final image is real, $\boxed{\text{10 cm beyond the second lens}}$. The distance has two significant figures.

(*b*) The total magnification is the product of the magnifications for the two lenses:

$$m = m_1 m_2 = \left(-\frac{d_{i1}}{d_{o1}}\right)\left(-\frac{d_{i2}}{d_{o2}}\right) = \frac{d_{i1} d_{i2}}{d_{o1} d_{o2}} = \frac{(30.0\,\text{cm})(10.0\,\text{cm})}{(60.0\,\text{cm})(-5.0\,\text{cm})} = \boxed{-1.0\times}$$

(*c*) See the diagram here.



26. We find the focal length of the combination by finding the image distance for an object very far away. For the converging lens, we have the following from Eq. 33-2.

$$\frac{1}{d_{o1}}+\frac{1}{d_{i1}}=\frac{1}{f_C}=\frac{1}{\infty}+\frac{1}{d_{i1}} \rightarrow d_{i1}=f_C$$

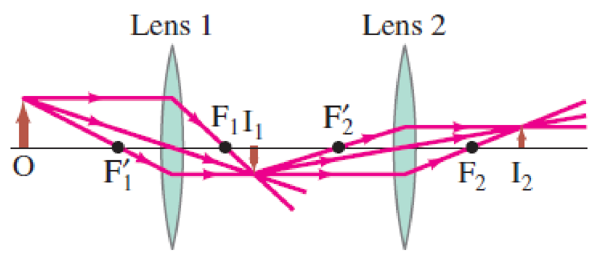
The first image is the object for the second lens. Since the first image is real, the second object distance is negative. We also assume that the lenses are thin, and so $d_{o2}=-d_{i1}=-f_C$.
For the second diverging lens, we have the following from Eq. 33-2.

$$\frac{1}{d_{o2}}+\frac{1}{d_{i2}}=\frac{1}{f_D}=-\frac{1}{f_C}+\frac{1}{d_{i2}}$$

Since the original object was at infinity, the second image must be at the focal point of the combination, and so $d_{i2}=f_T$.

$$\frac{1}{f_D}=-\frac{1}{f_C}+\frac{1}{d_{i2}}=-\frac{1}{f_C}+\frac{1}{f_T}$$

27. (*a*) We see that the image is real and upright. We estimate that it is 30 cm beyond the second lens, and that the final image height is half the original object height.



(*b*) Find the image formed by the first lens, using Eq. 33-2.

$$\frac{1}{d_{o1}}+\frac{1}{d_{i1}}=\frac{1}{f_1} \rightarrow$$

$$d_{i1}=\frac{d_{o1}f_1}{d_{o1}-f_1}=\frac{(36\,\text{cm})(13\,\text{cm})}{(36\,\text{cm})-(13\,\text{cm})}=20.35\,\text{cm}$$

This image is the object for the second lens. Because it is between the lenses, it has a positive object distance.

$$d_{o2}=56\,\text{cm}-20.35\,\text{cm}=35.65\,\text{cm}$$

Find the image formed by the second lens, again using Eq. 33-2.

$$\frac{1}{d_{o2}}+\frac{1}{d_{i2}}=\frac{1}{f_2} \rightarrow d_{i2}=\frac{d_{o2}f_2}{d_{o2}-f_2}=\frac{(35.65\,\text{cm})(16\,\text{cm})}{(35.65\,\text{cm})-(16\,\text{cm})}=29.25\,\text{cm}$$

Thus the final image is real, 29 cm beyond the second lens.
The total magnification is the product of the magnifications for the two lenses:

$$m=m_1m_2=\left(-\frac{d_{i1}}{d_{o1}}\right)\left(-\frac{d_{i2}}{d_{o2}}\right)=\frac{(20.35\,\text{cm})(29.25\,\text{cm})}{(36\,\text{cm})(35.65\,\text{cm})}=\boxed{0.46\times}$$

28. Use Eq. 33-4, the lensmaker's equation.

$$\frac{1}{f}=(n-1)\left(\frac{1}{R_1}+\frac{1}{R_2}\right)\rightarrow$$

$$f=\frac{1}{(n-1)}\left(\frac{R_1R_2}{R_1+R_2}\right)=\frac{1}{(1.58-1)}\left(\frac{(-33.4\,\text{cm})(-28.8\,\text{cm})}{(-33.4\,\text{cm})+(-28.8\,\text{cm})}\right)=-26.66\,\text{cm}\approx\boxed{-27\,\text{cm}}$$

29. Find the index from Eq. 33-4, the lensmaker's equation.

$$\frac{1}{f}=(n-1)\left(\frac{1}{R_1}+\frac{1}{R_2}\right)\rightarrow n=1+\frac{1}{f}\left(\frac{R_1R_2}{R_1+R_2}\right)=1+\left(\frac{1}{28.9\,\text{cm}}\right)\left(\tfrac{1}{2}(31.4\,\text{cm})\right)=\boxed{1.54}$$

30. With the surfaces reversed, we have $R_1=-46.2\,\text{cm}$ and $R_2=+22.4\,\text{cm}$. Use Eq. 33-4 to find the focal length.

$$\frac{1}{f}=(n-1)\left(\frac{1}{R_1}+\frac{1}{R_2}\right)\rightarrow$$

$$f=\frac{1}{(n-1)}\left(\frac{R_1R_2}{R_1+R_2}\right)=\frac{1}{(1.50-1)}\left(\frac{(-46.2\,\text{cm})(+22.4\,\text{cm})}{(-46.2\,\text{cm})+(+22.4\,\text{cm})}\right)=\boxed{87.0\,\text{cm}}$$

31. The plane surface has an infinite radius of curvature. Let the plane surface be surface 2, so $R_2=\infty$. The index of refraction is found in Table 32-1.

$$\frac{1}{f}=(n-1)\left(\frac{1}{R_1}+\frac{1}{R_2}\right)=\frac{1}{f}=(n-1)\left(\frac{1}{R_1}+\frac{1}{\infty}\right)=\frac{(n-1)}{R_1}\rightarrow$$

$$R_1=(n-1)f=(1.46-1)(18.7\,\text{cm})=\boxed{8.6\,\text{cm}}$$

32. First we find the focal length from Eq. 33-3, the lensmaker's equation. Then we use Eq. 33-2 to find the image distance, and Eq. 33-3 to find the magnification.

$$\frac{1}{f}=(n-1)\left(\frac{1}{R_1}+\frac{1}{R_2}\right)\rightarrow$$

$$f=\frac{1}{(n-1)}\left(\frac{R_1R_2}{R_1+R_2}\right)=\frac{1}{(1.52-1)}\left(\frac{(-22.0\,\text{cm})(+18.5\,\text{cm})}{(-22.0\,\text{cm})+(+18.5\,\text{cm})}\right)=223.6\,\text{cm}$$

$$\frac{1}{d_o}+\frac{1}{d_i}=\frac{1}{f}\rightarrow d_i=\frac{d_o f}{d_o-f}=\frac{(90.0\,\text{cm})(223.6\,\text{m})}{90.0\,\text{cm}-223.6\,\text{cm}}=-150.6\,\text{cm}\approx\boxed{-151\,\text{cm}}$$

$$m=-\frac{d_i}{d_o}=-\frac{-150.6\,\text{cm}}{90.0\,\text{cm}}=\boxed{+1.67}$$

The image is virtual, in front of the lens, and upright.

33. Find the radius from the lensmaker's equation, Eq. 33-4.:

$$\frac{1}{f}=(n-1)\left(\frac{1}{R_1}+\frac{1}{R_2}\right)\rightarrow P=(n-1)\left(\frac{1}{R_1}+\frac{1}{R_2}\right)\rightarrow$$

$$R_2=\frac{(n-1)R_1}{PR_1-(n-1)}=\frac{(1.56-1)(0.300\,\text{m})}{(3.50\,\text{D})(0.300\,\text{m})-(1.56-1)}=\boxed{0.34\,\text{m}}$$

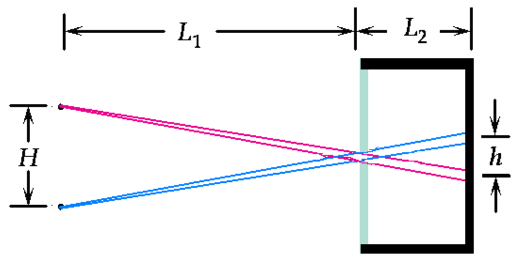
34. The exposure is proportional to the product of the lens opening area and the exposure time, with the square of the *f*-stop number inversely proportional to the lens opening area. Setting the exposures equal for both exposure times we solve for the needed *f*-stop number.

$$t_1(f\text{-stop}_1)^{-2} = t_2(f\text{-stop}_2)^{-2} \rightarrow f\text{-stop}_2 = f\text{-stop}_1\sqrt{\frac{t_2}{t_1}} = 16\sqrt{\frac{1/1000\text{ s}}{1/120\text{s}}} = 5.54 \text{ or } \boxed{\frac{f}{5.6}}$$

35. We find the *f*-number from $f\text{-stop} = f/D$.

$$f\text{-stop} = \frac{f}{D} = \frac{(17\text{cm})}{(6.0\text{cm})} = \boxed{\frac{f}{2.8}}$$

36. We use similar triangles, created from the distances between the centers of the two objects (*H*) and their ray traces to the hole (L_1) and the distance between the centers of the two images (*h*) and the distance of the screen to the hole (L_2) to determine the distance between the center of the two image circles. We then create similar triangles from the two ray traces for a single source with the base of one triangle equal to the diameter of the hole (*d*) , and the base of the second triangle equal to the diameter of the image circle (*D*). The heights for these two triangles are the distance from object to hole (L_1) and the distance from object to image ($L_1 + L_2$).



$$\frac{H}{L_1} = \frac{h}{L_2} \rightarrow h = H\frac{L_2}{L_1} = (2.0\text{ cm})\frac{7.0\text{ cm}}{100\text{ cm}} = 0.14\text{ cm} = 1.4\text{ mm}$$

$$\frac{d}{L_1} = \frac{D}{L_1 + L_2} \rightarrow D = d\frac{L_1 + L_2}{L_1} = (1.0\text{mm})\frac{100\text{cm} + 7.0\text{cm}}{100\text{cm}} = 1.07\text{mm}$$

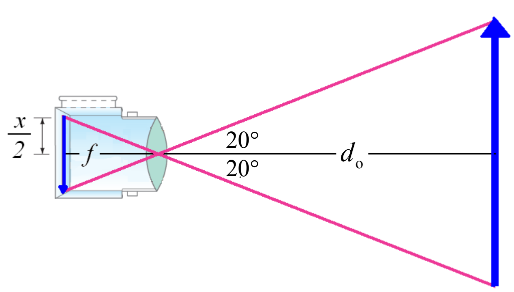
Since the separation distance of the two images is greater than their diameters, the two circles do not overlap.

37. We calculate the effective *f*-number for the pinhole camera by dividing the focal length by the diameter of the pinhole. The focal length is equal to the image distance. Setting the exposures equal for both cameras, where the exposure is proportional to the product of the exposure time and the area of the lens opening (which is inversely proportional to the square of the *f*-stop number), we solve for the exposure time.

$$f\text{-stop}_2 = \frac{f}{D} = \frac{(70\text{mm})}{(1.0\text{mm})} = \frac{f}{70}.$$

$$t_1(f\text{-stop}_1)^{-2} = t_2(f\text{-stop}_2)^{-2} \rightarrow t_2 = t_1\left(\frac{f\text{-stop}_2}{f\text{-stop}_1}\right)^2 = \frac{1}{250\text{ s}}\left(\frac{70}{11}\right)^2 = 0.16\text{ s} \approx \boxed{\tfrac{1}{6}\text{s}}$$

38. Consider an object located a distance d_o from a converging lens of focal length f and its real image formed at distance d_i. If the distance d_o is much greater than the focal length, the lens equation tells us that the focal length and image distance are equal.



$$\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f} \rightarrow d_i = \frac{fd_o}{d_o - f} \approx \frac{fd_o}{d_o} = f$$

Thus, in a camera, the recording medium of spatial extent x is placed a distance equal to f behind the lens to form a focused image of a distant object. Assume the distant object subtends an angle of 40° at the position of the lens, so that the half-angle subtended is 20°, as shown in the figure. We then use the tangent of this angle to determine the relationship between the focal length and half the image height.

$$\tan 20^\circ = \frac{\frac{1}{2}x}{f} \rightarrow f = \frac{x}{2\tan 20^\circ}$$

(*a*) For a 35-mm camera, we set $x = 36\text{ mm}$ to calculate the focal length.

$$f = \frac{36\text{ mm}}{2\tan 20^\circ} = \boxed{49\text{ mm}}$$

(*b*) For a digital camera, we set $x = 1.0\text{ cm} = 10\text{ mm}$.

$$f = \frac{10\text{ mm}}{2\tan 20^\circ} = \boxed{14\text{ mm}}$$

39. The image distance is found from Eq. 33-3, and then the focal length from Eq. 33-2. The image is inverted.

$$m = \frac{h_i}{h_o} = -\frac{d_i}{d_o} \rightarrow d_i = -d_o\frac{h_i}{h_o} = -(65\text{m})\frac{(-24\text{mm})}{(38\text{m})} = 41\text{mm}$$

$$\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f} \rightarrow f = \frac{d_o d_i}{d_o + d_i} = \frac{(65\text{m})(0.041\text{m})}{65\text{m} - 0.041\text{m}} = 0.041\text{m} = \boxed{41\text{mm}}$$

The object is essentially at infinity, so the image distance is equal to the focal length.

40. The length of the eyeball is the image distance for a far object, i.e., the focal length of the lens. We find the *f*-number from $f\text{-stop} = f/D$.

$$f\text{-stop} = \frac{f}{D} = \frac{(20\text{mm})}{(8.0\text{mm})} = \boxed{2.5 \text{ or } \frac{f}{2.5}}.$$

41. The actual near point of the person is 55 cm. With the lens, an object placed at the normal near point, 25 cm, or 23 cm from the lens, is to produce a virtual image 55 cm from the eye, or 53 cm from the lens. We find the power of the lens from Eqs. 33-1 and 33-3.

$$P = \frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{0.23\text{m}} + \frac{1}{-0.53\text{m}} = \boxed{2.5\text{D}}$$

42. The screen placed 55 cm from the eye, or 53.2 cm from the lens, is to produce a virtual image 105 cm from the eye, or 103.2 cm from the lens. Find the power of the lens from Eqs. 33-1 and 33-2.

$$P = \frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{0.532\text{m}} + \frac{1}{-1.032\text{m}} = \boxed{0.91\text{D}}$$

43. With the contact lens, an object at infinity should form a virtual image at the far point of the eye, 17 cm from the contact lens. Use that with Eq. 33-2 to find the focal length of the contact lens. We find the power of the lens from

$$\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f} \rightarrow \frac{1}{\infty} + \frac{1}{d_i} = \frac{1}{f} \rightarrow f = d_i = -17\text{cm}$$

Find the new near point as the object location that forms a virtual image at the actual near point of 12 cm from the contact lens. Again use Eq. 33-2.

$$\frac{1}{d_o}+\frac{1}{d_i}=\frac{1}{f} \rightarrow d_o=\frac{fd_i}{d_i-f}=\frac{(-17\,\text{cm})(-12\,\text{cm})}{(-12\,\text{cm})-(-17\,\text{cm})}=\boxed{41\,\text{cm}}$$

So the person would have to hold the object 41 cm from their eye to see it clearly. With glasses, they only had to hold the object 32 cm from the eye. So $\boxed{\text{glasses would be better.}}$

44. (*a*) Since the lens power is negative, the lens is diverging, so it produces images closer than the object. Thus the person is $\boxed{\text{nearsighted.}}$

(*b*) We find the far point by finding the image distance for an object at infinity. Since the lens is 2.0 cm in front of the eye, the far point is 2.0 cm farther than the absolute value of the image distance.

$$\frac{1}{d_o}+\frac{1}{d_i}=\frac{1}{f}=P \rightarrow \frac{1}{\infty}+\frac{1}{d_i}=-4.50\,\text{D} \rightarrow d_i=-\frac{1}{4.50\ \text{D}}=-0.222\ \text{m}=-22.2\ \text{cm}$$

$$\text{FP}=\left|-22.2\ \text{cm}\right|+2.0\ \text{cm}=\boxed{24.2\ \text{cm}}\ \text{from eye}$$

45. (*a*) The lens should put the image of an object at infinity at the person's far point of 78 cm. Note that the image is still in front of the eye, so the image distance is negative. Use Eqs. 33-2 and 33-1.

$$P=\frac{1}{f}=\frac{1}{d_o}+\frac{1}{d_i}=\frac{1}{\infty}+\frac{1}{(-0.78\,\text{m})}=-1.282\,\text{D}\approx\boxed{-1.3\,\text{D}}$$

(*b*) To find the near point with the lens in place, we find the object distance to form an image 25 cm in front of the eye.

$$\frac{1}{d_o}+\frac{1}{d_i}=\frac{1}{f}=P \rightarrow d_o=\frac{d_i}{Pd_i-1}=\frac{(-0.25\,\text{m})}{(-1.282\,\text{D})(-0.25\,\text{m})-1}=0.37\,\text{m}=\boxed{37\,\text{cm}}$$

46. The image of an object at infinity is to be formed 14 cm in front of the eye. So for glasses, the image distance is to be $d_i=-12\,\text{cm}$, and for contact lenses, the image distance is to be $d_i=-14\,\text{cm}$.

$$\frac{1}{d_o}+\frac{1}{d_i}=\frac{1}{f}=\frac{1}{\infty}+\frac{1}{d_i} \rightarrow f=d_i \rightarrow P=\frac{1}{f}=\frac{1}{d_i}$$

$$P_{\text{glasses}}=\frac{1}{-0.12\,\text{m}}=\boxed{-8.3\,\text{D}}\ ;\ P_{\text{contacts}}=\frac{1}{-0.14\,\text{m}}=\boxed{-7.1\,\text{D}}$$

47. Find the far point of the eye by finding the image distance FROM THE LENS for an object at infinity, using Eq. 33-2.

$$\frac{1}{d_{o1}}+\frac{1}{d_{i1}}=\frac{1}{f_1} \rightarrow \frac{1}{\infty}+\frac{1}{d_{i1}}=\frac{1}{f_1} \rightarrow d_{i1}=f_1=-23.0\,\text{cm}$$

Since the image is 23.0 in front of the lens, the image is 24.8 cm in front of the eye. The contact lens must put the image of an object at infinity at this same location. Use Eq. 33-2 for the contact lens with an image distance of -24.8 cm and an object distance of infinity.

$$\frac{1}{d_{o2}}+\frac{1}{d_{i2}}=\frac{1}{f_2} \rightarrow \frac{1}{\infty}+\frac{1}{d_{i2}}=\frac{1}{f_1} \rightarrow f_1=d_{i2}=\boxed{-24.8\,\text{cm}}$$

48. (*a*) We find the focal length of the lens for an object at infinity and the image on the retina. The image distance is thus 2.0 cm. Use Eq. 33-2.

$$\frac{1}{d_o}+\frac{1}{d_i}=\frac{1}{f} \rightarrow \frac{1}{\infty}+\frac{1}{2.0\,\text{cm}}=\frac{1}{f} \rightarrow f=\boxed{2.0\,\text{cm}}$$

(*b*) We find the focal length of the lens for an object distance of 38 cm and an image distance of 2.0 cm. Again use Eq. 33.2.

$$\frac{1}{d_o}+\frac{1}{d_i}=\frac{1}{f} \rightarrow f=\frac{d_o d_i}{d_o+d_i}=\frac{(38\,\text{cm})(2.0\,\text{cm})}{(38\,\text{cm})+(2.0\,\text{cm})}=\boxed{1.9\,\text{cm}}$$

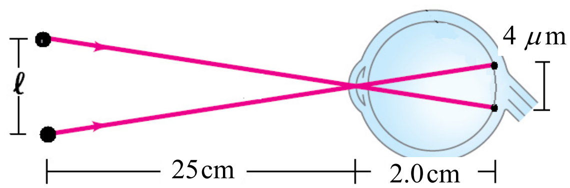
49. Find the object distance for the contact lens to form an image at the eye's near point, using Eqs. 33-2 and 33-1.

$$\frac{1}{d_o}+\frac{1}{d_i}=\frac{1}{f}=P \rightarrow d_o=\frac{d_i}{Pd_i-1}=\frac{-0.106\,\text{m}}{(-4.00\,\text{D})(-0.106\,\text{m})-1}=0.184\,\text{m}=\boxed{18.4\,\text{cm}}$$

Likewise find the object distance for the contact lens to form an image at the eye's far point.

$$d_o=\frac{d_i}{Pd_i-1}=\frac{-0.200\,\text{m}}{(-4.0\,\text{D})(-0.200\,\text{m})-1}=1.00\,\text{m}=\boxed{100\,\text{cm}}\ \text{(3 sig. fig.)}$$

50. In the image we show the principal rays from each of the two points as they pass directly through the cornea and onto the lens. These two rays and the distance between the two objects, ℓ, and the distance between the two images (4 μm) create similar triangles. We set the ratio of the bases and heights of these two triangles equal to solve for ℓ.



$$\frac{\ell}{25\text{ cm}}=\frac{4\ \mu\text{m}}{2.0\text{ cm}} \rightarrow \ell=25\text{ cm}\,\frac{4\ \mu\text{m}}{2.0\text{ cm}}=\boxed{50\,\mu\text{m}}$$

51. We find the focal length from Eq. 33-6

$$M=\frac{N}{f} \rightarrow f=\frac{N}{M}=\frac{25\,\text{cm}}{3.8}=\boxed{6.6\,\text{cm}}$$

52. Find the magnification from Eq. 33-6.

$$M=\frac{N}{f}=\frac{(25\,\text{cm})}{(13\,\text{cm})}=\boxed{1.9\times}$$

53. (*a*) We find the focal length with the image at the near point from Eq. 33-6b.

$$M=1+\frac{N}{f} \rightarrow f=\frac{N}{M-1}=\frac{25\,\text{cm}}{3.0-1}=12.5\,\text{cm}\approx\boxed{13\,\text{cm}}$$

$$3.0=1+\frac{(25\,\text{cm})}{f_1},\ \text{which gives}\ f_1=12.5\,\text{cm}\approx\boxed{13\,\text{cm.}}$$

(*b*) If the eye is relaxed, the image is at infinity, and so use Eq. 33-6a.

$$M=\frac{N}{f} \rightarrow f=\frac{N}{M}=\frac{25\,\text{cm}}{3.0}=\boxed{8.3\,\text{cm}}$$

54. Maximum magnification is obtained with the image at the near point (which is negative). We find the object distance from Eq. 33-2, and the magnification from Eq. 33-6b.

$$\frac{1}{d_o}+\frac{1}{d_i}=\frac{1}{f} \rightarrow d_o=\frac{d_i f}{d_i-f}=\frac{(-25.0\,\text{cm})(8.80\,\text{cm})}{(-25.0\,\text{cm})-(8.80\,\text{cm})}=\boxed{6.51\,\text{cm}}$$

$$M = 1 + \frac{N}{f} = 1 + \frac{25.0\,\text{cm}}{8.80\,\text{cm}} = \boxed{3.84\times}$$

55. (*a*) We find the image distance from Eq. 33-2.

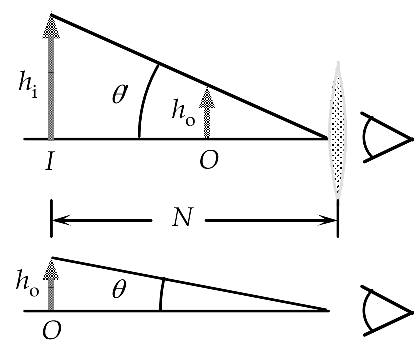
$$\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f} \rightarrow d_i = \frac{fd_o}{d_o - f} = \frac{(6.00\,\text{cm})(5.85\,\text{cm})}{5.85\,\text{cm} - 6.00\,\text{cm}} = \boxed{-234\,\text{cm}}$$

(*b*) The angular magnification is given by Eq. 33-6a, since the eye will have to focus over 2 m away.

$$M = \frac{N}{f} = \frac{25.0\,\text{cm}}{6.00\,\text{cm}} = \boxed{4.17\times}$$

56. (*a*) We use Eq. 33-6b to calculate the angular magnification.

$$M = 1 + \frac{N}{f} = 1 + \frac{(25.0\,\text{cm})}{(9.60\,\text{cm})} = \boxed{3.60\times}$$



(*b*) Because the object without the lens and the image with the lens are at the near point, the angular magnification is also the ratio of widths. Using this relationship we calculate the image width.

$$M = \frac{h_i}{h_o} \rightarrow h_i = Mh_o = 3.60(3.40\,\text{mm}) = \boxed{12.3\,\text{mm}}$$

(*c*) We use Eq. 33-2 to calculate the object distance, with the image distance at -25.0 cm.

$$\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f} \rightarrow d_o = \frac{fd_i}{d_i - f} = \frac{(9.60\,\text{cm})(-25.0\,\text{cm})}{-25.0\,\text{cm} - 9.60\,\text{cm}} = \boxed{6.94\,\text{cm}}$$

57. (*a*) We find the image distance using Eq. 33-2.

$$\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f} \rightarrow d_i = \frac{fd_o}{d_o - f} = \frac{(9.5\,\text{cm})(8.3\,\text{cm})}{8.3\,\text{cm} - 9.5\,\text{cm}} = \boxed{-66\,\text{cm}}$$

(*b*) The angular magnification is found using Eq. 33-5, with the angles given as defined in Figure 33-33.

$$M = \frac{\theta'}{\theta} = \frac{(h_o/d_o)}{(h_o/N)} = \frac{N}{d_o} = \frac{25\text{ cm}}{8.3\text{ cm}} = \boxed{3.0\times}$$

58. First, find the focal length of the magnifying glass from Eq. 33-6a, for a relaxed eye (focused at infinity).

$$M = \frac{N}{f} \rightarrow f = \frac{N}{M} = \frac{25.0\,\text{cm}}{3.0} = 8.33\,\text{cm}$$

(*a*) Again use Eq. 33-6a for a different near point.

$$M_1 = \frac{N_1}{f} = \frac{(65\,\text{cm})}{(8.33\,\text{cm})} = \boxed{7.8\times}$$

(*b*) Again use Eq. 33-6a for a different near point.

$$M_2 = \frac{N_2}{f} = \frac{(17\,\text{cm})}{(8.33\,\text{cm})} = \boxed{2.0\times}$$

Without the lens, the closest an object can be placed is the near point. A farther near point means a smaller angle subtended by the object without the lens, and thus greater magnification.

59. The focal length is 10 cm. First, find the object distance for an image at infinity. Then, find the object distance for an image 25 cm in front of the eye.

Initial: $\frac{1}{d_o}+\frac{1}{d_i}=\frac{1}{f} \rightarrow \frac{1}{d_o}+\frac{1}{\infty}=\frac{1}{f} \rightarrow d_o=f=12\,\text{cm}$

Final: $\frac{1}{d_o}+\frac{1}{d_i}=\frac{1}{f} \rightarrow d_o=\frac{d_i f}{d_i-f}=\frac{(-25\,\text{cm})(12\,\text{cm})}{(-25\,\text{cm})-(12\,\text{cm})}=8.1\,\text{cm}$

The lens was moved $12\,\text{cm}-8.1\,\text{cm}=3.9\,\text{cm}\approx$ $\boxed{\text{4 cm toward the fine print}}$.

60. The magnification of the telescope is given by Eq. 33-7.

$$M=-\frac{f_o}{f_e}=-\frac{(78\,\text{cm})}{(2.8\,\text{cm})}=\boxed{-28\times}$$

For both object and image far away, the separation of the lenses is the sum of the focal lengths.

$$f_o+f_e=78\,\text{cm}+2.8\,\text{cm}=\boxed{81\,\text{cm}}$$

$\boxed{61.}$ We find the focal length of the eyepiece from the magnification by Eq. 33-7.

$$M=-\frac{f_o}{f_e} \rightarrow f_e=-\frac{f_o}{M}=-\frac{88\,\text{cm}}{35\times}=\boxed{2.5\,\text{cm}}$$

For both object and image far away, the separation of the lenses is the sum of the focal lengths.

$$f_o+f_e=88\,\text{cm}+2.5\,\text{cm}=\boxed{91\,\text{cm}}$$

62. We find the focal length of the objective from Eq. 33-7.

$$M=f_o/f_e \rightarrow f_o=Mf_e=(7.0)(3.0\,\text{cm})=\boxed{21\,\text{cm}}$$

63. The magnification is given by Eq. 33-7.

$$M=-f_o/f_e==-f_oP_e=-(0.75\,\text{m})(35\,\text{D})=\boxed{-26\times}$$

64. For a distant object and a relaxed eye (which means the image is at infinity), the separation of the eyepiece and objective lenses is the sum of their focal lengths. Use Eq. 33-7 to find the magnification.

$$\ell=f_o+f_e\ ;\ M=-\frac{f_o}{f_e}=-\frac{f_o}{\ell-f_o}=-\frac{75.5\,\text{cm}}{78.0\,\text{cm}-75.5\,\text{cm}}=\boxed{-30\times}$$

65. For a distant object and a relaxed eye (which means the image is at infinity), the separation of the eyepiece and objective lenses is the sum of their focal lengths. Use Eq. 33-7 to find the magnification.

$$\ell=f_o+f_e\ ;\ M=-\frac{f_o}{f_e}=-\frac{f_o}{\ell-f_o}=-\frac{36.0\,\text{cm}}{33.8\,\text{cm}-36.0\,\text{cm}}=\boxed{+16\times}$$

66. The focal length of the objective is just half the radius of curvature. Use Eq. 33-7 for the magnification.

$$M=-\frac{f_o}{f_e}=-\frac{\frac{1}{2}r}{f_e}=-\frac{3.2\,\text{m}}{0.028\text{m}}=-114\times\approx\boxed{-110\times}$$

67. The focal length of the mirror is found from Eq. 33-7. The radius of curvature is twice the focal length.

$$M = -\frac{f_o}{f_e} \rightarrow f_o = -Mf_e = -(120)(0.031\,\text{m}) = 3.72\,\text{m} \approx \boxed{3.7\,\text{m}} \;;\; r = 2f = \boxed{7.4\,\text{m}}$$

68. The relaxed eye means that the image is at infinity, and so the distance between the two lenses is 1.25 m. Use that relationship with Eq. 33-7 to solve for the focal lengths. Note that the magnification for an astronomical telescope is negative.

$$\ell = f_o + f_e \;;\; M = -\frac{f_o}{f_e} = -\frac{f_o}{\ell - f_o} \rightarrow f_o = \frac{M\ell}{M-1} = \frac{-120(1.25\,\text{m})}{-120-1} = \boxed{1.24\,\text{m}}$$

$$f_e = \ell - f_o = 1.25\,\text{m} - 1.24\,\text{m} = 0.01\,\text{m} = \boxed{1\text{ cm}}$$

69. We use Eq. 33-6a and the magnification of the eyepiece to calculate the focal length of the eyepiece. We set the sum of the focal lengths equal to the length of the telescope to calculate the focal length of the objective. Then using both focal lengths in Eq. 33-7 we calculate the maximum magnification.

$$f_e = \frac{N}{M} = \frac{25\,\text{cm}}{5} = 5\,\text{cm} \;;\; \ell = f_e + f_o \rightarrow f_o = \ell - f_e = 50\,\text{cm} - 5\,\text{cm} = 45\,\text{cm}$$

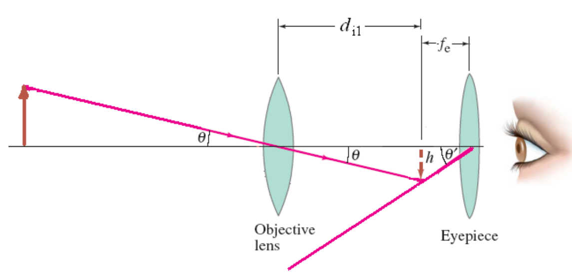
$$M = -\frac{f_o}{f_e} = -\frac{45\,\text{cm}}{5\,\text{cm}} = \boxed{-9\times}$$

70. Since the star is very far away, the image of the star from the objective mirror will be at the focal length of the objective, which is equal to one-half its radius of curvature (Eq. 32-1). We subtract this distance from the separation distance to determine the object distance for the second mirror. Then, using Eq. 33-2, we calculate the final image distance, which is where the sensor should be placed.

$$d_{i1} = f_o = \frac{R_o}{2} = \frac{3.00\,\text{m}}{2} = 1.50\,\text{m} \;;\; d_{o2} = \ell - d_{i1} = 0.90\,\text{m} - 1.50\,\text{m} = -0.60\,\text{m}$$

$$\frac{1}{d_{o2}} + \frac{1}{d_{i2}} = \frac{1}{f_e} = \frac{2}{R_e} \rightarrow d_i = \frac{R_e d_{o2}}{2d_{o2} - R_e} = \frac{(-1.50\,\text{m})(-0.60\,\text{m})}{2(-0.60\,\text{m}) - (-1.50\,\text{m})} = \boxed{3.0\,\text{m}}$$

71. We assume a prism binocular so the magnification is positive, but simplify the diagram by ignoring the prisms. We find the focal length of the eyepiece using Eq. 33-7, with the design magnification.



$$f_e = \frac{f_o}{M} = \frac{26\,\text{cm}}{7.5} = 3.47\,\text{cm}$$

Using Eq. 33-2 and the objective focal length, we calculate the intermediate image distance. With the final image at infinity (relaxed eye), the secondary object distance is equal to the focal length of the eyepiece. We calculate the angular magnification using Eq. 33-5, with the angles shown in the diagram.

$$\frac{1}{d_{o1}} + \frac{1}{d_{i1}} = \frac{1}{f_o} \rightarrow d_{i1} = \frac{f_o d_{o`}}{d_{o1} - f_o} = \frac{(26\,\text{cm})(400\,\text{cm})}{400\,\text{cm} - 26\,\text{cm}} = 27.81\,\text{cm}$$

$$M = \frac{\theta'}{\theta} = \frac{h/f_e}{h/d_{i1}} = \frac{d_{i1}}{f_e} = \frac{27.81\,\text{cm}}{3.47\,\text{cm}} = \boxed{8.0\times}$$

72. The magnification of the microscope is given by Eq. 33-10b.

$$M=\frac{N\ell}{f_{\mathrm{o}}f_{\mathrm{e}}}=\frac{(25\,\mathrm{cm})(17.5\,\mathrm{cm})}{(0.65\,\mathrm{cm})(1.50\,\mathrm{cm})}=448.7\times\approx\boxed{450\times}$$

73. We find the focal length of the eyepiece from the magnification of the microscope, using the approximate results of Eq. 33-10b. We already know that $f_{\mathrm{o}}\ll\ell$.

$$M\approx\frac{N\ell}{f_{\mathrm{o}}f_{\mathrm{e}}}\;\rightarrow\;f_{\mathrm{e}}=\frac{N\ell}{Mf_{\mathrm{o}}}=\frac{(25\,\mathrm{cm})(17.5\,\mathrm{cm})}{(680)(0.40\,\mathrm{cm})}=\boxed{1.6\,\mathrm{cm}}$$

Note that this also satisfies the assumption that $f_{\mathrm{e}}\ll\ell$.

74. We use Eq. 33-10b.

$$M\approx\frac{N\ell}{f_{\mathrm{e}}f_{\mathrm{o}}}=\frac{(25\,\mathrm{cm})(17\,\mathrm{cm})}{(2.5\,\mathrm{cm})(0.28\,\mathrm{cm})}=607.1\times\approx\boxed{610\times}$$

75. (*a*) The total magnification is found from Eq. 33-10a.

$$M=M_{\mathrm{o}}M_{\mathrm{e}}=(58.0)(13.0)=\boxed{754\times}$$

(*b*) With the final image at infinity, we find the focal length of the eyepiece using Eq. 33-9.

$$M_{\mathrm{e}}=\frac{N}{f_{\mathrm{e}}}\;\rightarrow\;f_{\mathrm{e}}=\frac{N}{M_{\mathrm{e}}}=\frac{25.0\,\mathrm{cm}}{13.0}=1.923\,\mathrm{cm}\approx\boxed{1.92\,\mathrm{cm}}$$

Since the image from the objective is at the focal point of the eyepiece, we set the image distance from the objective as the distance between the lenses less the focal length of the eyepiece. Using the image distance and magnification in Eq. 33-3, we calculate the initial object distance. Then using the image and object distance in Eq. 33-2 we calculate the objective focal length.

$$d_{\mathrm{i}}=\ell-f_{\mathrm{e}}=20.0\,\mathrm{cm}-1.92\,\mathrm{cm}=18.08\,\mathrm{cm}$$

$$m=\frac{d_{\mathrm{i}}}{d_{\mathrm{o}}}\rightarrow d_{\mathrm{o}}=\frac{d_{\mathrm{i}}}{m}=\frac{18.08\,\mathrm{cm}}{58.0}=0.312\,\mathrm{cm}$$

$$\frac{1}{f_{\mathrm{o}}}=\frac{1}{d_{\mathrm{o}}}+\frac{1}{d_{\mathrm{i}}}\rightarrow f_{\mathrm{o}}=\frac{d_{\mathrm{o}}d_{\mathrm{i}}}{d_{\mathrm{o}}+d_{\mathrm{i}}}=\frac{(0.312\,\mathrm{cm})(18.08\,\mathrm{cm})}{0.312\,\mathrm{cm}+18.08\,\mathrm{cm}}=\boxed{0.307\,\mathrm{cm}}$$

(*c*) We found the object distance, in part (*b*), $d_{\mathrm{o}}=\boxed{0.312\,\mathrm{cm}}$.

76. (*a*) The total magnification is the product of the magnification of each lens, with the magnification of the eyepiece increased by one, as in Eq. 33-6b.

$$M=M_{\mathrm{o}}(M_{\mathrm{e}}+1)=(58.0)(13.0+1.0)=\boxed{812\times}$$

(*b*) We find the focal length of the eyepiece using Eq. 33-6b.

$$(M_{\mathrm{e}}+1)=\frac{N}{f_{\mathrm{e}}}+1\;\rightarrow\;f_{\mathrm{e}}=\frac{N}{M_{\mathrm{e}}}=\frac{25\,\mathrm{cm}}{13.0}=\boxed{1.92\,\mathrm{cm}}$$

Since the image from the eyepiece is at the near point, we use Eq. 33-2 to calculate the location of the object. This object distance is the location of the image from the objective. Subtracting this object distance from the distance between the lenses gives us the image distance from the objective. Using the image distance and magnification in Eq. 33-3, we calculate the initial object distance. Then using the image and object distance in Eq. 33-2 we calculate the objective focal length.

$$\frac{1}{f_e}=\frac{1}{d_{o2}}+\frac{1}{d_{i2}} \rightarrow d_{o2}=\frac{f_e d_{i2}}{d_{i2}-f_e}=\frac{(1.92\,\text{cm})(-25.0\,\text{cm})}{-25.0\,\text{cm}-1.92\,\text{cm}}=1.78\,\text{cm}$$

$$d_{i1}=\ell-d_{o2}=20.0\,\text{cm}-1.78\,\text{cm}=18.22\,\text{cm}$$

$$m=\frac{d_i}{d_o} \rightarrow d_o=\frac{d_i}{m}=\frac{18.22\,\text{cm}}{58.0}=0.314\,\text{cm}$$

$$\frac{1}{f_o}=\frac{1}{d_o}+\frac{1}{d_i} \rightarrow f_o=\frac{d_o d_i}{d_o+d_i}=\frac{(0.314\,\text{cm})(18.22\,\text{cm})}{0.314\,\text{cm}+18.22\,\text{cm}}=\boxed{0.308\,\text{cm}}$$

(*c*) We found the object distance, in part (*b*), $d_o=\boxed{0.314\,\text{cm}}$.

77. (*a*) Since the final image is at infinity (relaxed eye) the image from the objective is at the focal point of the eyepiece. We subtract this distance from the distance between the lenses to calculate the objective image distance. Then using Eq. 33-2, we calculate the object distance.

$$d_{i1}=\ell-f_e=16.8\,\text{cm}-1.8\,\text{cm}=15.0\,\text{cm}$$

$$\frac{1}{f_o}=\frac{1}{d_{o1}}+\frac{1}{d_{i1}} \rightarrow d_{o1}=\frac{f_o d_{i1}}{d_{i1}-f_o}=\frac{(0.80\,\text{cm})(15.0\,\text{cm})}{15.0\,\text{cm}-0.80\,\text{cm}}=\boxed{0.85\,\text{cm}}$$

(*b*) With the final image at infinity, the magnification of the eyepiece is given by Eq. 33-10a.

$$M=\frac{N}{f_e}\left(\frac{\ell-f_e}{d_o}\right)=\frac{(25.0\,\text{cm})}{(1.8\,\text{cm})}\left(\frac{16.8\,\text{cm}-1.8\,\text{cm}}{0.85\,\text{cm}}\right)=247\times\approx\boxed{250\times}$$

78. (*a*) We find the image distance from the objective using Eq. 33-2. For the final image to be at infinity (viewed with a relaxed eye), the objective image distance must be at the focal distance of the eyepiece. We calculate the distance between the lenses as the sum of the objective image distance and the eyepiece focal length.

$$\frac{1}{d_{o1}}+\frac{1}{d_{i1}}=\frac{1}{f_o} \rightarrow d_{i1}=\frac{f_o d_{o1}}{d_{o1}-f_o}=\frac{(0.740\,\text{cm})(0.790\,\text{cm})}{0.790\,\text{cm}-0.740\,\text{cm}}=11.7\,\text{cm}$$

$$\ell=d_{i1}+f_e=11.7\,\text{cm}+2.80\,\text{cm}=\boxed{14.5\,\text{cm}}$$

(*b*) We use Eq. 33-10a to calculate the total magnification.

$$M=\frac{N}{f_e}\left(\frac{\ell-f_e}{d_o}\right)=\frac{(25.0\,\text{cm})}{(2.80\,\text{cm})}\left(\frac{14.5\,\text{cm}-2.80\,\text{cm}}{0.790\,\text{cm}}\right)=\boxed{132\times}$$

79. For each objective lens we set the image distance equal to the sum of the focal length and 160 mm. Then, using Eq. 33-2 we write a relation for the object distance in terms of the focal length. Using this relation in Eq. 33-3 we write an equation for the magnification in terms of the objective focal length. The total magnification is the product of the magnification of the objective and focal length.

$$\frac{1}{d_o}+\frac{1}{d_i}=\frac{1}{f_o} \rightarrow \frac{1}{d_o}=\frac{1}{f_o}-\frac{1}{d_i} \rightarrow \frac{1}{d_o}=\frac{1}{f_o}-\frac{1}{f_o+160\text{ mm}} \rightarrow d_o=\frac{f_o(f_o+160\text{ mm})}{160\text{ mm}}$$

$$m_o=\frac{d_i}{d_o}=\frac{f_o+160\,\text{mm}}{\left[\dfrac{f_o(f_o+160\,\text{mm})}{160\text{ mm}}\right]}=\frac{160\text{ mm}}{f_o}$$

Since the objective magnification is inversely proportional to the focal length, the objective with the smallest focal length $(f_o=3.9\text{ mm})$ combined with the largest eyepiece magnification $(M_e=10)$ yields the largest overall magnification. The objective with the largest focal length $(f_o=32\text{ mm})$

coupled with the smallest eyepiece magnification $(M_e = 5)$ yields the smallest overall magnification.

$$M_{largest} = \frac{160\,\text{mm}}{3.9\,\text{mm}}(10\times) = \boxed{410\times}\ ;\ M_{smallest} = \frac{160\,\text{mm}}{32\,\text{mm}}(5\times) = \boxed{25\times}$$

80. (*a*) For this microscope both the objective and eyepiece have focal lengths of 12 cm. Since the final image is at infinity (relaxed eye) the image from the objective must be at the focal length of the eyepiece. The objective image distance must therefore be equal to the distance between the lenses less the focal length of the objective. We calculate the object distance by inserting the objective focal length and image distance into Eq. 33-2.

$$d_{i1} = \ell - f_e = 55\,\text{cm} - 12\,\text{cm} = 43\,\text{cm}$$

$$\frac{1}{f_o} = \frac{1}{d_o} + \frac{1}{d_{i1}} \rightarrow d_o = \frac{f_o d_{i1}}{d_{i1} - f_o} = \frac{(12\,\text{cm})(43\,\text{cm})}{43\,\text{cm} - 12\,\text{cm}} = 16.65\,\text{cm} \approx \boxed{17\,\text{cm}}$$

(*b*) We calculate the magnification using Eq. 33-10a.

$$M = \frac{N}{f_e}\left(\frac{\ell - f_e}{d_o}\right) = \frac{(25\,\text{cm})}{(12\,\text{cm})}\left(\frac{55\,\text{cm} - 12\,\text{cm}}{16.65\,\text{cm}}\right) = 5.38\times \approx \boxed{5.4\times}$$

(*c*) We calculate the magnification using Eq. 33-10b, and divide the result by the answer to part (*b*) to determine the percent difference.

$$M_{approx} \approx \frac{N\ell}{f_e f_o} = \frac{(25\,\text{cm})(55\,\text{cm})}{(12\,\text{cm})(\ 12\,\text{cm})} = 9.55\times\ ;\ \frac{M_{approx} - M}{M} = \frac{9.55 - 5.38}{5.38} = 0.775 \approx \boxed{78\%}$$

81. We use Eq. 33-4 to find the focal length for each color, and then Eq. 33-2 to find the image distance. For the plano-convex lens, $R_1 > 0$ and $R_2 = \infty$.

$$\frac{1}{f_{red}} = (n_{red} - 1)\left(\frac{1}{R_1} + \frac{1}{R_2}\right) = (1.5106 - 1)\left[\left(\frac{1}{18.4\,\text{cm}}\right) + \left(\frac{1}{\infty}\right)\right] \rightarrow f_{red} = 36.036\,\text{cm}$$

$$\frac{1}{f_{yellow}} = (n_{yellow} - 1)\left(\frac{1}{R_1} + \frac{1}{R_2}\right) = (1.5226 - 1)\left[\left(\frac{1}{18.4\,\text{cm}}\right) + \left(\frac{1}{\infty}\right)\right] \rightarrow f_{orange} = 35.209\,\text{cm}$$

We find the image distances from

$$\frac{1}{d_o} + \frac{1}{d_{i_{red}}} = \frac{1}{f_{red}} \rightarrow d_{i_{red}} = \frac{d_o f_{red}}{d_o - f_{red}} = \frac{(66.0\,\text{cm})(36.036\,\text{cm})}{(66.0\,\text{cm}) - (36.036\,\text{cm})} = 79.374\,\text{cm} \approx \boxed{79.4\,\text{cm}}$$

$$\frac{1}{d_o} + \frac{1}{d_{i_{yellow}}} = \frac{1}{f_{yellow}} \rightarrow d_{i_{yellow}} = \frac{d_o f_{yellow}}{d_o - f_{yellow}} = \frac{(66.0\,\text{cm})(35.209\,\text{cm})}{(66.0\,\text{cm}) - (35.209\,\text{cm})} = 75.469\,\text{cm} \approx \boxed{75.5\,\text{cm}}$$

The images are 3.9 cm apart, an example of chromatic aberration.

82. From Problem 26 we have a relationship between the individual focal lengths and the focal length of the combination.

$$\frac{1}{f_D} = -\frac{1}{f_C} + \frac{1}{f_T} \rightarrow \frac{1}{f_T} = \frac{1}{f_D} + \frac{1}{f_C} \rightarrow f_T = \frac{f_C f_D}{f_C + f_D} = \frac{(25\,\text{cm})(-28\,\text{cm})}{(25\,\text{cm}) + (-28\,\text{cm})} = 233\,\text{cm}$$

(*a*) The combination is $\boxed{\text{converging}}$, since the focal length is positive. Also, the converging lens is "stronger" than the diverging lens since it has a smaller absolute focal length (or higher absolute power).

(*b*) From above, $f_T \approx \boxed{230\,\text{cm}}$.

83. We calculate the range object distances from Eq. 33-2 using the given focal length and maximum and minimum image distances.

$$\frac{1}{f}=\frac{1}{d_o}+\frac{1}{d_i} \rightarrow d_{o,min}=\frac{fd_{i,max}}{d_{i,max}-f}=\frac{(200.0\,mm)(206.4\,mm)}{206.4\,mm-200.0\,mm}=6450\,mm=6.45\,m$$

$$d_{o,max}=\frac{fd_{i,min}}{d_{i,min}-f}=\frac{(200.0\,mm)(200.0\,mm)}{200.0\,mm-200.0\,mm}=\infty$$

Thus the range of object distances is $\boxed{6.45\,m \le d_o < \infty}$.

84. We calculate the maximum and minimum image distances from Eq. 33-2, using the given focal length and maximum and minimum object distances. Subtracting these two distances gives the distance over which the lens must move relative to the plane of the sensor or film.

$$\frac{1}{f}=\frac{1}{d_o}+\frac{1}{d_i} \rightarrow d_{i,max}=\frac{fd_{o,min}}{d_{o,min}-f}=\frac{(135\,mm)(1.30\,m)}{1300\,mm-135\,mm}=0.151\,m=151\,mm$$

$$d_{i,min}=\frac{fd_{o,max}}{d_{o,max}-f}=\frac{(135\,mm)(\infty)}{\infty-135\,mm}=135\,mm$$

$$\Delta d=d_{i,max}-d_{i,min}=151\,mm-135\,mm=\boxed{16\,mm}$$

85. Since the object height is equal to the image height, the magnification is –1. We use Eq. 33-3 to obtain the image distance in terms of the object distance. Then we use this relationship with Eq. 33-2 to solve for the object distance.

$$m=-1=-\frac{d_i}{d_o} \rightarrow d_i=d_o$$

$$\frac{1}{f}=\frac{1}{d_o}+\frac{1}{d_i}=\frac{1}{d_o}+\frac{1}{d_o}=\frac{2}{d_o} \rightarrow d_o=2f=2(58\,mm)=\boxed{116\,mm}$$

The distance between the object and the film is the sum of the object and image distances.

$$d=d_o+d_i=d_o+d_o=2d_o=2(116\text{ mm})=\boxed{232\,mm}$$

86. When an object is very far away, the image will be at the focal point. We set the image distance in Eq. 33-3 equal to the focal length to show that the magnification is proportional to the focal length.

$$m=-\frac{d_i}{d_o}=-\frac{f}{d_o}=\left(-\frac{1}{d_o}\right)f=(\text{constant})f \rightarrow \boxed{m \propto f}$$

87. We use Eq. 33-2 with the final image distance and focal length of the converging lens to determine the location of the object for the second lens. Subtracting this distance from the separation distance between the lenses gives us the image distance from the first lens. Inserting this image distance and object distance into Eq. 33-2, we calculate the focal length of the diverging lens.

$$\frac{1}{d_{o2}}+\frac{1}{d_{i2}}=\frac{1}{f_2} \rightarrow d_{o2}=\frac{d_{i2}f_2}{d_{i2}-f_2}=\frac{(17.0\,cm)(12.0\,cm)}{17.0\,cm-12.0\,cm}=40.8\,cm$$

$$d_{i1}=\ell-d_{o2}=30.0\,cm-40.8\,cm=-10.8\,cm$$

$$\frac{1}{d_{o1}}+\frac{1}{d_{i1}}=\frac{1}{f_1} \rightarrow f_1=\frac{d_{i1}d_{o1}}{d_{i1}+d_{o1}}=\frac{(-10.8\,cm)(25.0\,cm)}{-10.8\,cm+25.0\,cm}=\boxed{-19.0\,cm}$$

88. The relationship between two lenses in contact was found in Problem 26. We use this resulting equation to solve for the combination focal length.

$$\frac{1}{f_T}=\frac{1}{f_D}+\frac{1}{f_C} \rightarrow f_T=\frac{f_D f_C}{f_D+f_C}=\frac{(-20.0\,\text{cm})(13.0\,\text{cm})}{-20.0\,\text{cm}+13.0\,\text{cm}}=\boxed{37.1\,\text{cm}}$$

Since the focal length is positive, the combination is a $\boxed{\text{converging lens}}$.

89. We use Eq. 33-7, which relates the magnification to the focal lengths, to write the focal length of the objective lens in terms of the magnification and focal length of the eyepiece. Then setting the sum of the focal lengths equal to the length of the telescope we solve for the focal length of the eyepiece and the focal length of the objective.

$$M=-\frac{f_o}{f_e} \rightarrow f_o=-Mf_e \;;\; \ell=f_e+f_o=f_e(1-M) \rightarrow f_e=\frac{\ell}{1-M}=\frac{28\,\text{cm}}{1-(-8.0)}=\boxed{3.1\,\text{cm}}$$

$$f_o=\ell-f_e=28\,\text{cm}-3.1\,\text{cm}=\boxed{25\,\text{cm}}$$

90. (*a*) When two lenses are placed in contact, the negative of the image of the first lens is the object distance of the second. Using Eq. 33-2, we solve for the image distance of the first lens. Inserting the negative of this image distance into the lens equation for the second lens we obtain a relationship between the initial object distance and final image distance. Again using the lens equation with this relationship, we obtain the focal length of the lens combination.

$$\frac{1}{f_1}=\frac{1}{d_{o1}}+\frac{1}{d_{i1}} \rightarrow \frac{1}{d_{i1}}=\frac{1}{f_1}-\frac{1}{d_{o1}}=-\frac{1}{d_{o2}}$$

$$\frac{1}{f_2}=\frac{1}{d_{o2}}+\frac{1}{d_{i2}}=\frac{1}{d_{o2}}-\left(\frac{1}{f_1}-\frac{1}{d_{o1}}\right)\Rightarrow\frac{1}{f_2}+\frac{1}{f_1}=\frac{1}{d_{o2}}+\frac{1}{d_{o1}}=\frac{1}{f_T}$$

$$\frac{1}{f_T}=\frac{1}{f_1}+\frac{1}{f_2} \rightarrow \boxed{f_T=\frac{f_1 f_2}{f_1+f_2}}$$

(*b*) Setting the power equal to the inverse of the focal length gives the relationship between powers of adjacent lenses.

$$\frac{1}{f_T}=\frac{1}{f_1}+\frac{1}{f_2}\Rightarrow\boxed{P_T=P_1+P_2}$$

91. (*a*) Because the Sun is very far away, the image will be at the focal point, or $d_i=f$. We find the magnitude of the size of the image using Eq. 33-3, with the image distance equal to 28 mm.

$$\frac{h_i}{h_o}=\frac{-d_i}{d_o} \rightarrow |h_i|=\frac{h_o d_i}{d_o}=\frac{(1.4\times10^6\,\text{km})(28\,\text{mm})}{1.5\times10^8\,\text{km}}=\boxed{0.26\,\text{mm}}$$

(*b*) We repeat the same calculation with a 50 mm image distance.

$$|h_i|=\frac{(1.4\times10^6\,\text{km})(50\,\text{mm})}{1.5\times10^8\,\text{km}}=\boxed{0.47\,\text{mm}}$$

(*c*) Again, with a 135 mm image distance.

$$|h_i|=\frac{(1.4\times10^6\,\text{km})(135\,\text{mm})}{1.5\times10^8\,\text{km}}=\boxed{1.3\text{ mm}}$$

(*d*) The equations show that image height is directly proportional to focal length. Therefore the relative magnifications will be the ratio of focal lengths.

$$\frac{28\,\text{mm}}{50\,\text{mm}}=\boxed{0.56\times}\text{ for the 28 mm lens ; }\frac{135\,\text{mm}}{50\,\text{mm}}=\boxed{2.7\times}\text{ for the 135 mm lens.}$$

92. We solve this problem by working through the lenses "backwards." We use the image distances and focal lengths to calculate the object distances. Since the final image from the right lens is halfway between the lenses, we set the image distance of the second lens equal to the negative of half the distance between the lenses. Using Eq. 33-2, we solve for the object distance of this lens. By subtracting this object distance from the distance between the two lenses, we find the image distance from the first lens. Then using Eq. 33-2 again, we solve for the initial object distance.

$$d_{i2} = -\tfrac{1}{2}\ell = -\tfrac{1}{2}(30.0\,\text{cm}) = -15.0\,\text{cm}$$

$$\frac{1}{d_{o2}} + \frac{1}{d_{i2}} = \frac{1}{f_2} \rightarrow d_{o2} = \frac{d_{i2}f_2}{d_{i2} - f_2} = \frac{(-15.0\,\text{cm})(20.0\,\text{cm})}{-15.0\,\text{cm} - 20.0\,\text{cm}} = 8.57\,\text{cm}$$

$$d_{i1} = \ell - d_{o2} = 30.0\text{ cm} - 8.57\text{ cm} = 21.4\text{ cm}$$

$$\frac{1}{d_{o1}} + \frac{1}{d_{i1}} = \frac{1}{f_1} \rightarrow d_{o1} = \frac{d_{i1}f_1}{d_{i1} - f_1} = \frac{(21.4\,\text{cm})(15.0\,\text{cm})}{21.4\,\text{cm} - 15.0\,\text{cm}} = \boxed{50.0\,\text{cm}}$$

93. We set d_i as the original image distance and $d_i + 10.0\,\text{cm}$ as the new image distance. Then using Eq. 33-2 for both cases, we eliminate the focal length and solve for the image distance. We insert the real image distance into the initial lens equation and solve for the focal length.

$$\frac{1}{d_{o1}} + \frac{1}{d_i} = \frac{1}{f} = \frac{1}{d_{o2}} + \frac{1}{d_i + 10.0\,\text{cm}} \rightarrow \frac{1}{d_{o1}} - \frac{1}{d_{o2}} = \frac{1}{d_i + 10.0\,\text{cm}} - \frac{1}{d_i} = \frac{-10.0\,\text{cm}}{d_i(d_i + 10.0\,\text{cm})}$$

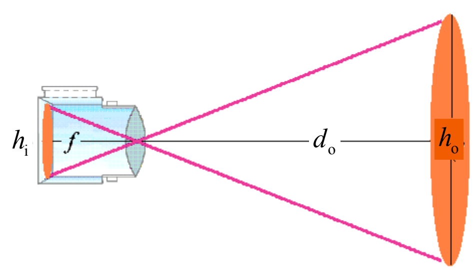
$$\frac{1}{60.0\,\text{cm}} - \frac{1}{40.0\,\text{cm}} = \frac{-10.0\,\text{cm}}{d_i(d_i + 10.0\,\text{cm})} \rightarrow d_i^2 + (10.0\,\text{cm})d_i - 1200\,\text{cm}^2 = 0$$

$$d_i = -40.0\,\text{cm} \text{ or } 30.0\,\text{cm}$$

Only the positive image distance will produce the real image.

$$\frac{1}{f} = \frac{1}{d_{o1}} + \frac{1}{d_i} \Rightarrow f = \frac{d_i d_{o1}}{d_i + d_{o1}} = \frac{(30.0\,\text{cm})(60.0\,\text{cm})}{30.0\,\text{cm} + 60.0\,\text{cm}} = \boxed{20.0\,\text{cm}}$$

94. Since the distance to the sun is much larger than the telescope's focal length, the image distance is about equal to the focal length. Rays from the top and bottom edges of the sun pass through the lens unrefracted. These rays with the object and image heights form similar triangles. We calculate the focal length of the telescope by setting the ratio of height to base for each triangle equal.



$$\frac{f}{h_i} = \frac{d_o}{h_o} \rightarrow$$

$$f = h_i\frac{d_o}{h_o} = (15\text{ mm})\frac{1.5\times10^8\text{ km}}{1.4\times10^6\text{ km}} = 1607\text{ mm} \approx \boxed{1.6\text{ m}}$$

95. We use Eq. 33-3 to write the image distance in terms of the object distance, image height, and object height. Then using Eq. 33-2 we solve for the object distance, which is the distance between the photographer and the subject.

$$m = \frac{h_i}{h_o} = -\frac{d_i}{d_o} \rightarrow \frac{1}{d_i} = -\frac{h_o}{h_i}\frac{1}{d_o}$$

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{d_o} + \left(-\frac{h_o}{h_i}\frac{1}{d_o}\right) = \left(1 - \frac{h_o}{h_i}\right)\frac{1}{d_o} \rightarrow$$

$$d_o = \left(1 - \frac{h_o}{h_i}\right) f = \left(1 - \frac{1750\,\text{mm}}{-8.25\,\text{mm}}\right)(220\,\text{mm}) = 46{,}900\,\text{mm} \approx \boxed{47\,\text{m}}$$

96. The exposure is proportional to the intensity of light, the area of the shutter, and the time. The area of the shutter is proportional to the square of the diameter or inversely proportional to the square of the *f*-stop. Setting the two proportionalities equal, with constant time, we solve for the change in intensity.

$$\frac{I_1 t}{(f\text{-stop}_1)^2} = \frac{I_2 t}{(f\text{-stop}_2)^2} \quad \rightarrow \quad \frac{I_2}{I_1} = \left(\frac{f\text{-stop}_2}{f\text{-stop}_1}\right)^2 = \left(\frac{16}{5.6}\right)^2 = \boxed{8.2}$$

97. The maximum magnification is achieved with the image at the near point, using Eq. 33-6b.

$$M_1 = 1 + \frac{N_1}{f} = 1 + \frac{(15.0\,\text{cm})}{(8.5\,\text{cm})} = \boxed{2.8\times}$$

For an adult we set the near point equal to 25.0 cm.

$$M_2 = 1 + \frac{N_2}{f} = 1 + \frac{(25.0\,\text{cm})}{(8.5\,\text{cm})} = \boxed{3.9\times}$$

The $\boxed{\text{person with the normal eye}}$ (adult) sees more detail.

98. The actual far point of the person is $155\,\text{cm}$. With the lens, an object far away is to produce a virtual image $155\,\text{cm}$ from the eye, or $153\,\text{cm}$ from the lens. We calculate the power of the upper part of the bifocals using Eq. 33-2 with the power equal to the inverse of the focal length in meter.

$$P_1 = \frac{1}{f_1} = \left(\frac{1}{d_{o1}}\right) + \left(\frac{1}{d_{i1}}\right) = \left(\frac{1}{\infty}\right) + \left(\frac{1}{-1.53\text{ m}}\right) = \boxed{-0.65\text{ D (upper part)}}$$

The actual near point of the person is $45\,\text{cm}$. With the lens, an object placed at the normal near point, 25 cm, or 23 cm from the lens, is to produce a virtual image $45\,\text{cm}$ from the eye, or $43\,\text{cm}$ from the lens. We again calculate the power using Eq. 33-2.

$$P_2 = \frac{1}{f_2} = \left(\frac{1}{d_{o2}}\right) + \left(\frac{1}{d_{i2}}\right) = \left(\frac{1}{0.23\text{ m}}\right) + \left(\frac{1}{-0.43\text{ m}}\right) = \boxed{+2.0\text{ D (lower part)}}$$

99. The magnification for a relaxed eye is given by Eq. 33-6a.

$$M = N/f = NP = (0.25\,\text{m})(+4.0\,\text{D}) = \boxed{1.0\times.}$$

100. (*a*) The magnification of the telescope is given by Eq. 33-7. The focal lengths are expressed in terms of their powers.

$$M = -\frac{f_o}{f_e} = -\frac{P_e}{P_o} = -\frac{(4.5\,\text{D})}{(2.0\,\text{D})} = -2.25\times \approx \boxed{-2.3\times}$$

(*b*) To get a magnification greater than 1, for the eyepiece we use the lens with the smaller focal length, or greater power: $\boxed{4.5\text{ D.}}$

101. We calculate the man's near point (d_i) using Eq. 33-2, with the initial object at 0.32 m with a 2.5 D lens. To give him a normal near point, we set the final object distance as 0.25 m and calculate the power necessary to have the image at his actual near point.

$$P_1 = \frac{1}{d_i} + \frac{1}{d_{o1}} \rightarrow \frac{1}{d_i} = P_1 - \frac{1}{d_{o1}} \rightarrow d_i = \frac{d_{o1}}{P_1 d_{o1} - 1} = \frac{0.32\,\text{m}}{(2.5\,\text{D})(0.32\,\text{m}) - 1} = -1.6\,\text{m}$$

$$P_2 = \frac{1}{d_i} + \frac{1}{d_{o2}} = \left(P_1 - \frac{1}{d_{o1}}\right) + \frac{1}{d_{o2}} = \left(+2.5\text{ D} - \frac{1}{0.32\text{ m}}\right) + \frac{1}{0.25\text{ m}} = \boxed{+3.4\text{ D}}$$

102. (*a*) We solve Eq. 33-2 for the image distance. Then taking the time derivative of the image distance gives the image velocity. If the velocity of the object is taken to be positive, then the image distance is decreasing, and so $v_o = -\frac{d}{dt}(d_o)$.

$$\frac{1}{f} = \frac{1}{d_i} + \frac{1}{d_o} \rightarrow d_i = \frac{f d_o}{d_o - f}$$

$$v_i = \frac{d}{dt}(d_i) = \frac{d}{dt}\left(\frac{f d_o}{d_o - f}\right) = \frac{f}{d_o - f}(-v_o) - \frac{f d_o}{(d_o - f)^2}(-v_o) = \frac{f(d_o - f) - f d_o}{(d_o - f)^2}(-v_o)$$

$$= \boxed{\frac{f^2 v_o}{(d_o - f)^2}}$$

(*b*) The velocity of the image is positive, which means the image is moving the same direction as the object. But since the image is on the opposite side of the lens as the object, the image must be moving away from the lens.

(*c*) We set the image and object velocities equal and solve for the image distance.

$$v_i = v_o \rightarrow \frac{f^2 v_o}{(d_o - f)^2} = v_o \rightarrow (d_o - f)^2 = f^2 \rightarrow d_o - f = f \rightarrow \boxed{d_o = 2f}$$

103. The focal length of the eyepiece is found using Eq. 33-1.

$$f_e = \frac{1}{P_e} = \frac{1}{23\text{ D}} = 4.3 \times 10^{-2}\text{ m} = 4.3\,\text{cm}.$$

For both object and image far away, we find the focal length of the objective from the separation of the lenses.

$$\ell = f_o + f_e \rightarrow f_o = \ell - f_e = 85\,\text{cm} - 4.3\,\text{cm} = 80.7\,\text{cm}$$

The magnification of the telescope is given by Eq. 33-7.

$$M = -\frac{f_o}{f_e} = -\frac{(80.7\,\text{cm})}{(4.3\,\text{cm})} = \boxed{-19\times}$$

104. (*a*) The length of the telescope is the sum of the focal lengths. The magnification is the ratio of the focal lengths (Eq. 33-7). For a magnification greater than one, the lens with the smaller focal length should be the eyepiece. Therefore the 4.0 cm lens should be the eyepiece.

$$\ell = f_o + f_e = 4.0\,\text{cm} + 44\,\text{cm} = \boxed{48\,\text{cm}}$$

$$M = -\frac{f_o}{f_e} = -\frac{(44\,\text{cm})}{(4.0\,\text{cm})} = \boxed{-11\times}$$

(*b*) We use Eq. 33-10b to solve for the length, ℓ, of the microscope.

$$M = -\frac{N\ell}{f_e f_o} \Rightarrow \ell = \frac{-M f_e f_o}{N} = \frac{-(25)(4.0\text{ cm})(44\text{ cm})}{25\text{ cm}} = 180\text{ cm} = \boxed{1.8\text{ m}}$$

This is far too long to be practical.

105. (*a*) The focal length of the lens is the inverse of the power.

$$f=\frac{1}{P}=\frac{1}{3.50\,\text{D}}=0.286\,\text{m}=\boxed{28.6\,\text{cm.}}$$

(*b*) The lens produces a virtual image at his near point. We set the object distance at 23 cm from the glass (25 cm from the eyes) and solve for the image distance. We add the two centimeters between the glass and eyes to determine the near point.

$$P=\frac{1}{f}=\frac{1}{d_\text{o}}+\frac{1}{d_\text{i}} \;\rightarrow\; d_\text{i}=\left(P-\frac{1}{d_\text{o}}\right)^{-1}=\left(3.50\,\text{D}-\frac{1}{0.23\,\text{m}}\right)^{-1}=-1.18\,\text{m}$$

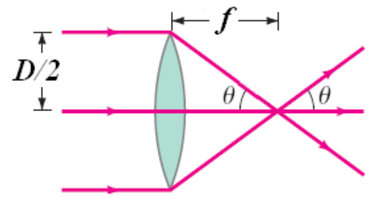
$$N=|d_i|+0.02\,\text{m}=1.18\,\text{m}+0.02\,\text{m}=\boxed{1.20\,\text{m}}$$

(*c*) For Pam, find the object distance that has an image at her near point, –0.23 m from the lens.

$$P=\frac{1}{f}=\frac{1}{d_\text{o}}+\frac{1}{d_\text{i}} \;\rightarrow\; d_\text{o}=\left(P-\frac{1}{d_\text{i}}\right)^{-1}=\left(3.50\text{ D}-\frac{1}{-0.23\text{ m}}\right)^{-1}=0.13\,\text{m}$$

Pam's near point with the glasses is 13 cm from the glasses or $\boxed{15\text{ cm}}$ from her eyes.

106. As shown in the image, the parallel rays will pass through a single point located at the focal distance from the lens. The ray passing through the edge of the lens (a distance D/2 from the principal axis) makes an angle θ with the principal axis. We set the tangent of this angle equal to the ratio of the opposite side (*D*/2) to the adjacent side (*f*) and solve for the focal length.



$$\tan\theta=\frac{D/2}{f}\rightarrow f=\frac{D}{2\tan\theta}=\frac{5.0\text{ cm}}{2\tan 3.5^\circ}=\boxed{41\text{ cm}}$$

107. We use Eq. 33-6b to calculate the necessary focal length for a magnifying glass held at the near point ($N=25\text{ cm}$) to have a magnification of $M=3.0$.

$$M=\frac{N}{f}+1 \;\rightarrow\; f=\frac{N}{M-1}=\frac{25\text{ cm}}{3.0-1}=12.5\text{ cm}$$

In the text, the lensmaker's equation (Eq. 33-4) is derived assuming the lens is composed of material with index of refraction n and is surrounded by air, whose index of refraction is $n_a=1$. We now modify this derivation, with the lens composed of air with index of refraction $n_a=1$ surrounded by water, whose index of refraction is $n_\text{w}=1.33$. In the proof of the lensmaker's equation, Snell's law at small angles is first applied at both surfaces of the lens.

$$n_\text{w}\sin\theta_1=n\sin\theta_2 \;\rightarrow\; n_\text{w}\theta_1\approx\theta_2 \;\rightarrow\; \theta_1\approx\frac{1}{n_\text{w}}\theta_2$$

$$n\sin\theta_3=n_\text{w}\sin\theta_4 \;\rightarrow\; \theta_3\approx n_\text{w}\theta_4 \;\rightarrow\; \frac{1}{n_\text{w}}\theta_3\approx\theta_4$$

These equations are the same as those following Fig. 33-16, but with *n* replaced by $1/n_w$. The rest of the derivation is the same, so we can rewrite the lensmaker's equation with this single modification. We assume the radii are equal, insert the necessary focal length, and solve for the radius of curvature

$$\frac{1}{f}=\left(\frac{1}{n_\text{w}}-1\right)\left[\frac{1}{R_1}+\frac{1}{R_2}\right]=\left(\frac{1}{n_\text{w}}-1\right)\left[\frac{1}{R}+\frac{1}{R}\right]=\left(\frac{1}{n_\text{w}}-1\right)\left[\frac{2}{R}\right]$$

$$R=2f\left(\frac{1}{n_\text{w}}-1\right)=2(12.5\text{ cm})\left(\frac{1}{1.33}-1\right)=-6.20\,\text{cm}\approx\boxed{-6.2\,\text{cm}}$$

The lens is therefore a $\boxed{\text{concave lens}}$ with radii of curvature –6.2 cm.

108. (*a*) We use Eq. 32-2 to calculate the image distance and then use the object and image distances in Eq. 32-3 to calculate the magnification. We finally make the approximation that the object distance is much larger than the focal length.

$$\frac{1}{d_o}+\frac{1}{d_i}=\frac{1}{f_1} \rightarrow d_i=\left(\frac{1}{f_1}-\frac{1}{d_o}\right)^{-1}=\frac{f_1 d_o}{d_o-f_1}$$

$$m_1=-\frac{d_i}{d_o}=-\frac{1}{d_o}\left(\frac{f_1 d_o}{d_o-f_1}\right)=-\frac{f_1}{d_o-f_1}\approx \boxed{-\frac{f_1}{d_o}}$$

This real image, located near the focal distance from lens 1, becomes the object for the second lens. We subtract the focal length from the separation distance to determine the object distance for lens 2. Using Eq. 32-2, we calculate the second image distance and Eq. 32-3 to calculate the second magnification. Multiplying the two magnifications gives the total magnification.

$$\frac{1}{d_{o2}}+\frac{1}{d_{i2}}=\frac{1}{f_2} \rightarrow d_{i2}=\frac{f_2 d_{o2}}{d_{o2}-f_2}$$

$$m_2=-\frac{d_{i2}}{d_{o2}}=-\frac{1}{d_{o2}}\left(\frac{f_2 d_{o2}}{d_{o2}-f_2}\right)=-\frac{f_2}{d_{o2}-f_2}=-\frac{\left(-\frac{1}{2}f_1\right)}{\left(\frac{3}{4}f_1-f_1\right)-\left(-\frac{1}{2}f_1\right)}=2$$

$$m_1 m_2=\left(-\frac{f_1}{d_o}\right)(2)=\boxed{-\frac{2f_1}{d_o}}$$

(*b*) If the object is at infinity, the image from the first lens will form a focal length behind that lens. Subtracting this distance from the separation distance gives the object distance for the second lens. We use Eq. 32-2 to calculate the image distance from the second lens. Adding this distance to the separation distance between the lenses gives the distance the image is from the first lens.

$$\frac{1}{d_{o2}}+\frac{1}{d_{i2}}=\frac{1}{f_2} \rightarrow d_{i2}=\frac{f_2 d_{o2}}{d_{o2}-f_2}=\frac{\left(-\frac{1}{2}f_1\right)\left(\frac{3}{4}f_1-f_1\right)}{\left(\frac{3}{4}f_1-f_1\right)-\left(-\frac{1}{2}f_1\right)}=\frac{1}{2}f_1$$

$$d=\ell+d_{i2}=\frac{3}{4}f_1+\frac{1}{2}f_1=\boxed{\frac{5}{4}f_1}$$

(*c*) We set the magnification equal to the total magnification found in part (*a*) and solve for the focal length.

$$m=-\frac{250\,\text{mm}}{d_o}=-\frac{2f_1}{d_o} \Rightarrow f_1=\frac{250\,\text{mm}}{2}=\boxed{125\,\text{mm}}$$

We use the results of part (*b*) to determine the distance of the lens to the film. We subtract this distance from 250 mm to determine how much closer the lens can be to the film in the two lens system.

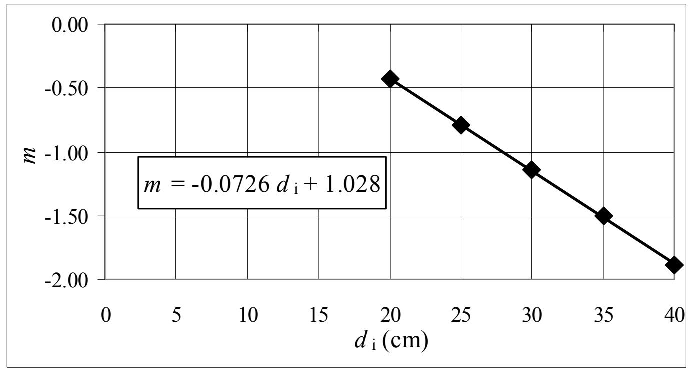
$$d=\frac{5}{4}f_1=\frac{5}{4}(125\,\text{mm})=\boxed{156\,\text{mm}} \;;\; \Delta d=250\,\text{mm}-156\,\text{mm}=\boxed{94\,\text{mm}}$$

109. (*a*) We use Eqs. 33-2 and 33-3.

$$m=-\frac{d_i}{d_o} \rightarrow d_o=-\frac{d_i}{m} \;;\; \frac{1}{d_o}+\frac{1}{d_i}=\frac{1}{f}=-\frac{m}{d_i}+\frac{1}{d_i} \rightarrow m=-\frac{d_i}{f}+1$$

This is a straight line with $\boxed{\text{slope}=-\frac{1}{f} \text{ and } y\text{-intercept}=1}$.

(*b*) A plot of m vs. d_i is shown here.



$$f = -\frac{1}{\text{slope}} = -\frac{1}{-.0726\,\text{cm}^{-1}} = 13.8\,\text{cm} \approx \boxed{14\,\text{cm}}$$

The y-intercept is 1.028. $\boxed{\text{Yes}}$, it is close to the expected value of 1. The spreadsheet used for this problem can be found on the Media Manager, with filename "PSE4_ISM_CH33.XLS," on tab "Problem 33.109b."

(*c*) Use the relationship derived above.

$$m = -\frac{d_i}{f} + 1 = -\frac{d' + \ell_i}{f} + 1 = -\frac{d_i'}{f} + \left(1 - \frac{\ell_i}{f}\right)$$

A plot of m vs. d_i' would still have a slope of $-\frac{1}{f}$, so $f = \boxed{-\frac{1}{\text{slope}}}$ as before. The y-intercept will have changed, to $1 - \frac{\ell_i}{f}$.