***Answer to Essential Question 24.9:*** If Figure 24.40 shows a focused image for the camera, the image location is where the film is in the camera. When the object is moved farther away, as in Figure 24.41, the lens must be moved to the right, closer to the film, so that the image is again focused on the film. This is shown in Figure 24.44.

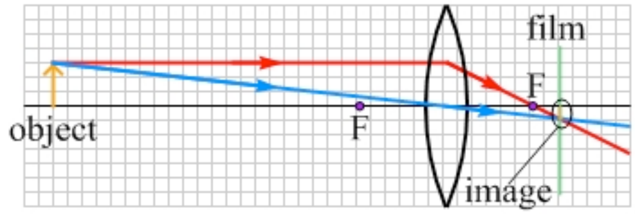


**Figure 24.44**: In a camera, the lens has a fixed shape, so the lens is moved to the right, closer to the film, when the object is moved farther from the camera. This produces a focused image on the film.

## *24-10 Multi-lens Systems*

How do we handle systems in which there is more than one lens (or more than one mirror, or combinations of mirrors and lenses)? The standard approach is to do the analysis one lens (or mirror) at a time. Starting from the object, follow the light until it reaches the first lens or mirror. Apply the methods we learned earlier to find the image created by the first lens or mirror. That image is then the object for the next lens or mirror in the sequence. Continue the process, one lens or mirror at a time, until we have followed the light through every lens or mirror.

**EXAMPLE 24.10 – Analyzing a two-lens system**

As shown in Figure 24.45, a toy train with a height of 4.0 cm is placed 24 cm from a converging lens that has a focal length of 8.0 cm. A second converging lens, identical to the first, is placed 18 cm from the first lens, and on the opposite side of the lens from the train.

(a) Calculate the position of the image created by the first lens, and sketch a ray diagram to support your calculations.

(b) Repeat part (a), but for the second lens, to find the final image.

(c) Determine the overall magnification of this two-lens system.

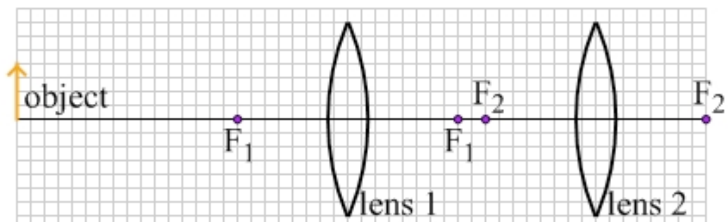


**Figure 24.45**: An object 24 cm in front of one lens, with a second lens 18 cm behind the first lens. Each box on the grid measures 1 cm × 1 cm.

**SOLUTION**

(a) To find the first image, let's apply the thin-lens equation. In this case, we get:

$$d_i = \frac{d_o \times f}{d_o - f} = \frac{(+24\text{ cm})\times(+8.0\text{ cm})}{24\text{ cm } - 8.0\text{ cm}} = \frac{192\text{ cm}^2}{16\text{ cm}} = 12\text{ cm}.$$

A ray diagram for this situation is shown in Figure 24.46, confirming the calculation above and showing that the image is real, inverted, and smaller than the object.

(b) We use the image produced by the first lens as the object for the second lens. The first thing we need to determine is the object distance for the second lens. If the image is 12 cm from the first lens, and the second lens is 18 cm from the first lens, then the image is only 6 cm (18 cm minus 12 cm)

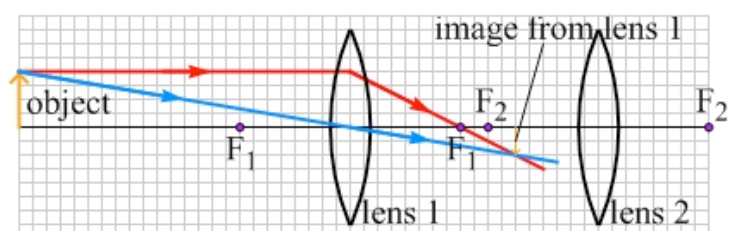


**Figure 24.46**: A ray diagram showing the real inverted image produced by the first lens. Each box on the grid measures 1 cm × 1 cm.

from the second lens (and is now the object for that lens). With an object distance of 6 cm, applying the thin-lens equation gives:

$$d_i = \frac{d_o \times f}{d_o - f} = \frac{(+6\text{ cm})\times(+8.0\text{ cm})}{6\text{ cm } -8.0\text{ cm}} = \frac{48\text{ cm}^2}{-2\text{ cm}} = -24\text{ cm}\,.$$

The ray diagram for this situation is shown in Figure 24.47, confirming the calculations.

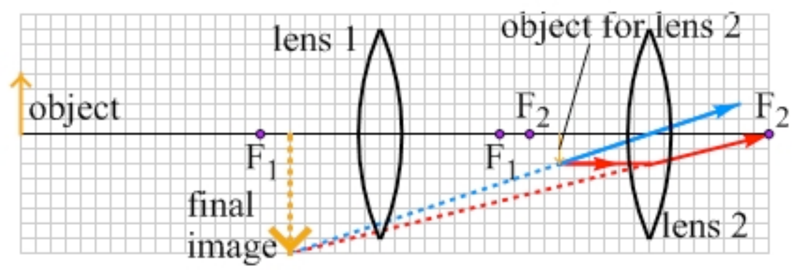


**Figure 24.47**: A ray diagram showing the image produced by the second lens. Each box on the grid measures 1 cm × 1 cm.

(c) We can determine the magnification in two different ways (which should give the same answer). First, the overall magnification is the ratio of the height of the final image to the height of the original object. We can find the heights of the two images by applying the magnification equation twice. For the first lens,

$m_1 = \frac{h_{i1}}{h_{o1}} = -\frac{d_{i1}}{d_{o1}} = -\frac{12\text{ cm}}{24\text{ cm}} = -0.5$, which, with an object height of 4.0 cm, gives an image height of –2.0 cm.

For the second lens,

$m_2 = \frac{h_{i2}}{h_{o2}} = -\frac{d_{i2}}{d_{o2}} = -\frac{(-24\text{ cm})}{6\text{ cm}} = +4.0$, which, with an object height of –2.0 cm, gives an image height of –8.0 cm.

Thus, the overall magnification is: $M = \frac{h_{i2}}{h_{o1}} = \frac{-8.0\text{ cm}}{4.0\text{ cm}} = -2.0$.

The final image is twice as large as the original object, with the minus sign telling us that the image is inverted compared to the original object.

The second way to find the overall magnification is to combine the magnifications of the individual lenses. The first lens gives an image that is inverted and half as large as the original object, while the second lens increases the size by a factor of four while maintaining the orientation. The overall magnification is the product of the individual magnifications:

$$M = m_1 \times m_2 = -0.5 \times (+4.0) = -2.0\,.$$

The method we applied here can be applied to any number of lenses and/or mirrors. Simply follow the light through the system, using the image created by one lens or mirror as the object for the next lens or mirror in the sequence.

**Related End-of-Chapter Exercises: 64, 65.**

***Essential Question 24.10:*** In an astronomical telescope, which uses two converging lenses, the distance between the lenses is the sum of the two focal lengths. Explain why this is the case.