5.3 The refracting telescope

Although real refracting telescopes have complex lens combinations to correct the image, for the purpose of understanding how they work it is sufficient to regard a telescope as consisting of two elements, the **objective** and the **eyepiece**, or **ocular**.

Figure 5.4 shows how an image is formed by a telescope. The object is very distant, and the objective forms an image of it at an image distance equal to its focal length. The eyepiece is set up so that its focal point practically coincides with that of the objective, so that the intermediate image will form an image at infinity as shown. But because the focal length of the eyepiece is smaller, the angular size of the final image is larger than the angular size of the object.

To calculate the angular magnification of the telescope, $m_\theta = \theta'/\theta$, we note first that

$$\theta = \angle BAD \approx \tan \angle BAD = \frac{h}{f_o} \tag{5.7}$$

Here f_o is the focal length of the objective, and h is the height of the image formed by the objective. Notice how the sign conventions apply here: h is negative because the image is oriented downwards, so $\theta = h/f_o$ is also negative, since $f_o > 0$ for a converging lens. This is consistent with the convention that angles are counted as positive going counterclockwise, so the angle θ' from the optical axis to the light ray is negative.

As for θ',

$$\theta' = \angle BCD \approx \tan \angle BCD = -\frac{h}{f_e} \tag{5.8}$$

Here f_e is the focal length of the eyepiece. The minus sign is necessary to make θ positive, because $h < 0$.

Now we can calculate the angular magnification as

$$m_\theta = \frac{\theta'}{\theta} = -\frac{f_o}{f_e} \tag{5.9}$$

The telescope forms an inverted image, which is sometimes undesirable. The **spyglass**, or **terrestrial telescope**, is used to observe objects closer to the observer. It is a variation on the telescope which produces an upright image. The essential difference is that the eyepiece is a *diverging lens*. Figure 5.5 shows the paths of the rays in this case.

Notice that the intermediate image formed by the objective lens falls to the right of the eyepiece. When this happens, this image is said to be a **virtual object** for the eyepiece. All this means is

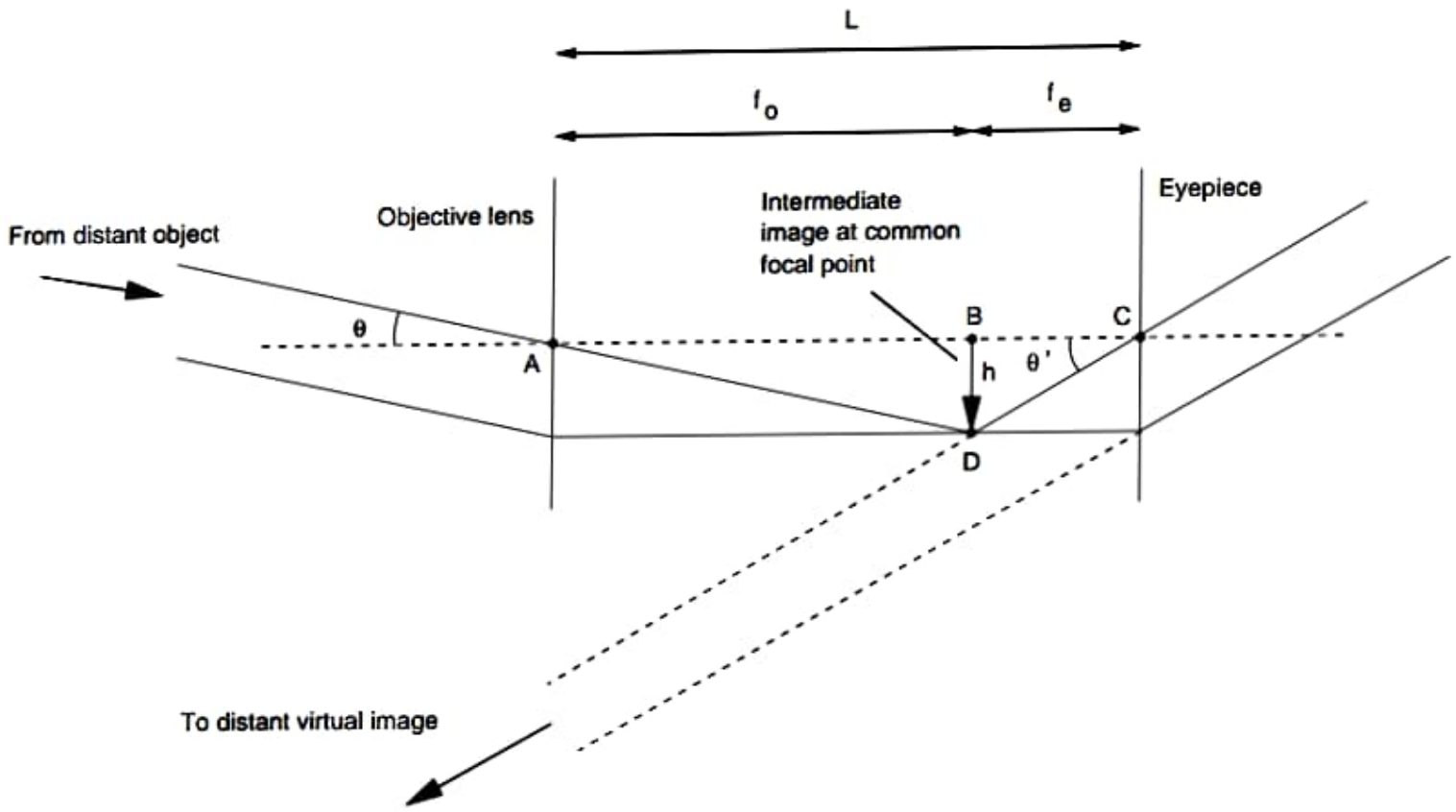

Figure 5.4: A refracting telescope.

that an image would be formed there if the eyepiece didn't exist. For the purpose of calculation, the object distance for the eyepiece is negative.

Remarkably, equations (5.7) and (5.8) still hold, so the angular magnification is still given by equation (5.9). But, since $f_e < 0$, the angular magnification is positive, which means that the final image is upright.