

**Answer to Essential Question 25.3:** A big difference between the sound waves and the light waves is the wavelength. The sound waves have wavelengths that are on the order of a meter, while the wavelengths of the light waves are about six orders of magnitude smaller. The width of the doorway is comparable to the wavelength of the sound waves, and so the sound waves experience significant diffraction. The doorway is so large compared to the wavelength of light, however, that the light goes in a straight line out the door, with negligible diffraction.

## 25-4 Diffraction: Double Slits and Circular Openings

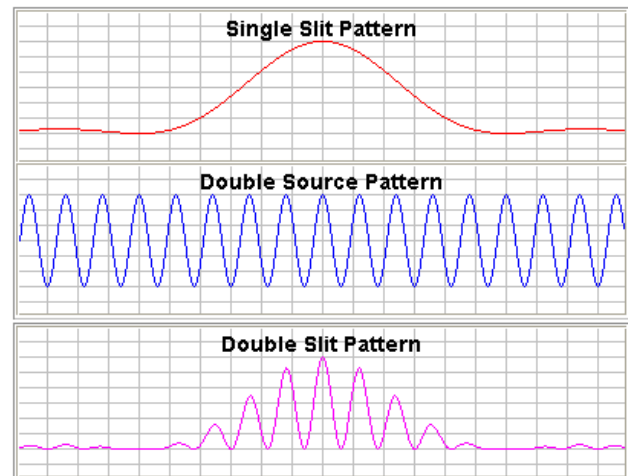
The bottom graph in Figure 25.16 shows the relative intensity, as a function of position, of the light striking a screen after passing through a double slit. If each slit acted as a source of light, emitting waves uniformly in all directions, we would expect the peaks on the screen to be equally bright, as shown in the “Double Source” picture. Instead, each opening emits a diffraction pattern, as shown in the “Single Slit” picture. The interference between the two diffraction patterns results in the “Double Slit” pattern at the bottom, with the amplitude of the peaks predicted by the double-source equation being reduced by a factor given by the single-slit equation.

The “Double Slit” pattern exhibits a phenomenon known as **missing orders**. Peaks that are predicted in the pattern by the double-source equation,  $d \sin\theta = m_d \lambda$ , coincide with zeros from the single-slit equation,  $a \sin\theta = m_s \lambda$ , and are thus missing from the pattern.

### A bit of history

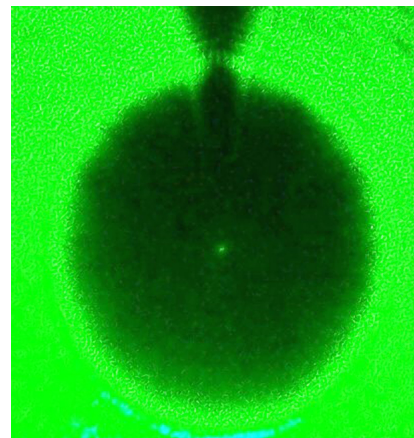
Prior to 1800, there was a big debate in physics about the nature of light. The Dutch scientist Christiaan Huygens (1629 – 1695) came up with a way to explain many optical phenomena (such as refraction) in terms of light acting as a wave. The main proponent of the particle theory, however, was Sir Isaac Newton (1643 – 1727), who called it the corpuscular theory. With the weight of Newton behind it, the particle model of light won out until Thomas Young’s double-slit experiment in 1801, followed by the work of the Frenchman, Augustin Fresnel, who studied diffraction in the early 1800’s.

In 1818, Siméon Poisson realized that if light acted as a wave, the shadow of a round object should have a bright spot at its center. The light would leave all points on the edge of the object, and constructively interfere to produce a bright spot at the center of the shadow, because that point has a path-length difference of zero. Poisson actually put forward the idea of the bright spot as a way to disprove the wave theory, so he was somewhat taken aback when Dominique Arago did an experiment to show that there really is such a bright spot. These days, it is easy to create the bright spot at the center of a shadow by diverging a laser beam with a lens and then shining the beam onto a smooth metal ball. The shadow produced by such an arrangement is shown in Figure 25.17.



**Figure 25.16:** When light passes through a double slit, the interference maxima are not equally bright, but drop off quite dramatically in brightness as you move away from the center of the pattern, as shown at the bottom. The double-slit pattern is a combination of the single-slit pattern (at the top) and the double-source pattern (in the middle).

**Figure 25.17:** The bright spot at the center of the shadow of a ball bearing, demonstrating that light acts as a wave. Photo credit: A. Duffy.



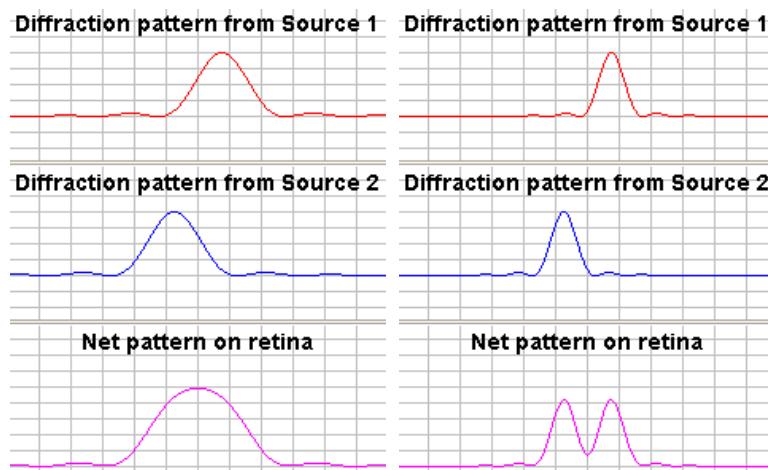
### Diffraction by a circular opening

A related and common phenomenon is diffraction by a circular opening (commonly called a circular aperture), such as the one we all look through, the pupil in each of our own eyes. For a circular opening, the angle at which the first zero occurs in a diffraction pattern is given by:

$$\theta_{\min} = \frac{1.22\lambda}{D} \quad (\text{Eq. 25.7: The first zero in a diffraction pattern from a circular aperture})$$

where  $D$  is the diameter of the opening. Note that the larger the diameter of the opening, the narrower the width of the central peak in the diffraction pattern. This dependence on the diameter of the opening has implications for how close two objects can be before you cannot resolve them. For instance, when you look up at the sky at night, two stars that are very close together may appear to you to be a single star. If you look at the same patch of sky through binoculars, or through a telescope, however, you can easily tell that you're looking at two separate stars. The light enters binoculars or telescopes through an aperture that is much larger than your pupil, and thus experiences much less diffraction.

It turns out that you can just resolve two objects when the first zero in the diffraction pattern associated with the first object coincides with the maximum in the diffraction pattern associated with the second object. Hence, Equation 25.7 gives the minimum angular separation between two objects such that you can just resolve them. Figure 25.18 illustrates the issue, where two objects are too close to be resolved by a human eye in bright sunlight, when the pupil is small, but can be resolved by the same eye when it is dark out, and the pupil has become larger to let in more light.



**Figure 25.18:** On the left, we see that the angular separation between two objects is too small for them to be resolved, with the patterns overlapping too much on the retina. The images on the left correspond to a human eye in bright sunlight, when the pupil is small. The images on the right correspond to the same situation, but viewed in the dark. In the dark, the pupil expands to let in more light, reducing the spreading associated with diffraction.

### Related End-of-Chapter Exercises: 9, 22, 23, and 46.

**Essential Question 25.4:** Consider the double-slit pattern in Figure 25.16. Noting the location of the missing orders in the pattern, what is the ratio of  $d$  to  $a$  for this double slit? That is the ratio of the center-to-center distance between the two openings ( $d$ ) to the width of each opening ( $a$ ).