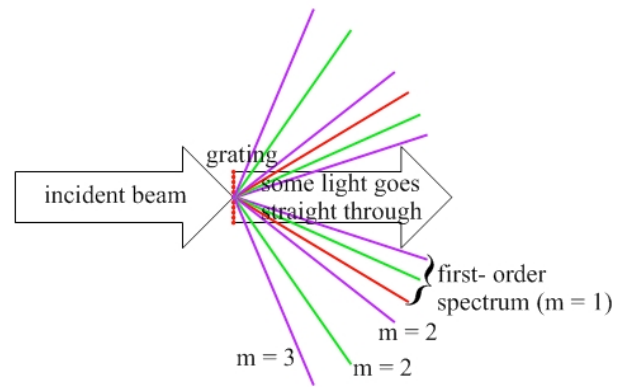


Answer to Essential Question 25.2: You might think that beams 1, 2, and 3 would also be violet, green, and red, respectively. However, in the equation $\sin\theta = m\lambda / d$, the right-hand side cannot exceed 1, because that is the limit on $\sin\theta$. If we use the three wavelengths with $m = 2$ or $m = 3$, we get the values shown in Table 25.1. It is possible to see the second-order violet and green lines, and the third-order violet lines, but none of the others because they correspond to values of $\sin\theta$ that are greater than 1, and are thus not possible. The beams are violet, green, and violet.



Order	Violet (400 nm)	Green (530 nm)	Red (660 nm)
$m = 2$	$\sin\theta = 800/1300$	$\sin\theta = 1060/1300$	$\sin\theta = 1320/1300$
$m = 3$	$\sin\theta = 1200/1300$	$\sin\theta = 1590/1300$	$\sin\theta = 1980/1300$

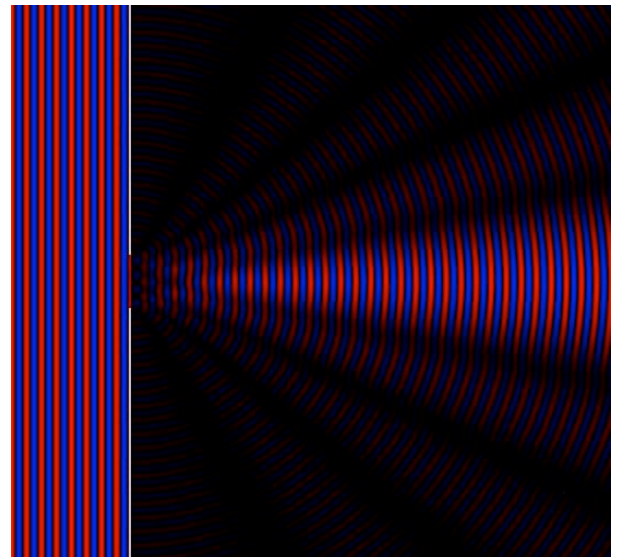
Table 25.1: Values of $\sin\theta$ for $m > 1$ for the situation of Essential Question 25.2.

Figure 25.11: The entire spectrum for the situation of Essential Question 25.2, showing how the light splits because of passing through the diffraction grating.

25-3 Diffraction from a Single Slit

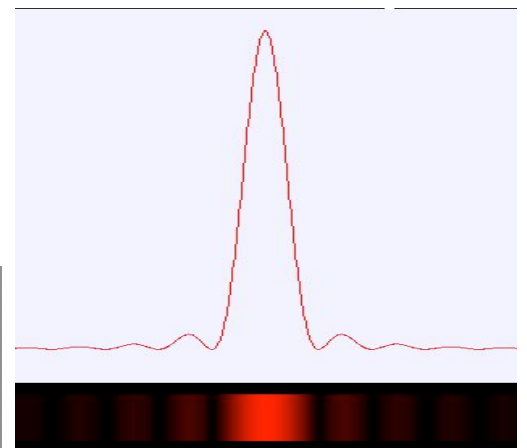
In Section 25-1, we considered what happens when two sources broadcasting identical waves interfere. With light, we typically shine a laser beam through two closely-spaced slits (a double slit, in other words). Each slit acts as a source of waves, but it turns out that each slit does not send out light uniformly in all directions. Instead, a wave passing through a slit (or striking an object) experiences **diffraction**. Each point on the opening, or on the object, acts as a source of waves, and the resulting diffraction pattern is the result of the interference between all these waves. As Figure 25.12 shows, the waves interfere constructively in the forward direction, with more destructive interference in most other directions.

Figure 25.12: The diffraction pattern that results from a plane wave striking an opening that is four wavelengths wide. In color, the picture has alternating red (representing peaks), and blue (represents troughs) regions, separated by black regions denotes zero, or small, amplitude.



The graph in Figure 25.13, and the corresponding picture underneath the graph that shows the diffraction pattern from a laser shining through a single slit, show how much of the wave's energy is concentrated in the forward direction. The secondary peaks have much less intensity than the central maximum. The central maximum is also twice as wide as are the secondary peaks, at least at small angles.

Figure 25.13: A graph of the intensity as a function of angle that corresponds to the diffraction pattern below the graph. The diffraction pattern comes from a laser shining on a single slit.



EXPLORATION 25.3 – An equation for the single slit

Step 1 – Return to Figure 25.2, which illustrates how waves from two sources can interfere constructively at a particular point if the path length difference is, for instance, one wavelength. Now turn this two-source situation into a single-slit situation by filling in the space between the original two sources with more sources. Figure 25.14 models a single-slit as being made up of a number of sources of waves laid out across the width of the opening. Note that while we use d to represent the distance between the two sources, we generally use a to represent the width of the single opening.

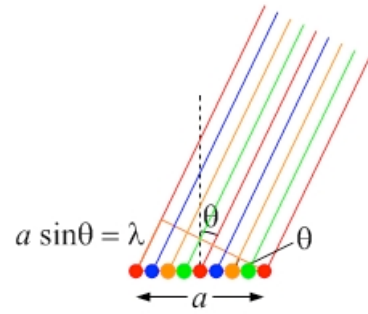


Figure 25.14: A modification of Figure 25.2, turning the double-source situation into a single-slit situation by filling the space between the original sources with additional sources.

Step 2 – The two sources in red that are at either end of the line of sources constructively interfere, in the situation shown, because their path-length difference is a full wavelength. What is the path-length difference for the source colored red that is in the middle of the set of sources, and the source at the left end of the line? What kind of interference is associated with these two sources? The path length for the left source is half a wavelength longer than the path length for the middle source, which corresponds to destructive interference.

Step 3 – What kind of interference results for the two blue sources, or the two orange sources, or the two green sources? The path-length difference for all these pairs of sources is half a wavelength, corresponding to destructive interference. For the point in question, the waves from the left half of the opening cancel the waves arriving from the right half of the opening.

Step 4 – If the equation $d \sin\theta = m\lambda$ gives the angles at which constructive interference occurs for two sources, what does the equation $a \sin\theta = m\lambda$ correspond to for the single slit? The equation $a \sin\theta = m\lambda$ gives the angles at which destructive interference occurs for the single slit.

$$a \sin\theta = m\lambda, \quad (\text{Equation 25.6: destructive interference for a single slit})$$

where m is an integer, and a is the width of the slit.

Key idea: The diffraction of waves passing through a single opening can be understood in terms of interference between waves leaving all points on the opening. The narrower the opening, the more the waves spread out. **Related End-of-Chapter Exercises: 19 – 21.**

Diffraction for sound waves

Diffraction takes place for other waves, such as water waves and sound waves, just as it does for light waves, with Equation 25.6 even applying for these other kinds of waves. Horn speakers, such as those shown in Figure 25.15, are often shaped to exploit diffraction, causing the waves to spread out in a particular dimension when they emerge from the end of the speaker.



Essential Question 25.3: As you are walking toward the open door to a room, you can hear the conversation between two people inside, even though you can't see the people. Explain why the sound waves are diffracted by the doorway, while the light is not.

Figure 25.15: These speakers are shaped to take advantage of diffraction for sound waves. The narrower the opening, the wider the diffraction pattern. The speakers are designed to diffract sound waves horizontally, where they can be heard by people on a train platform. Photo credit: A. Duffy.