***Answer to Essential Question 21.6***: When a source and an observer move in the same direction with the same speed, the observed frequency is the same as the frequency emitted by the source.

## *21-7 Superposition and Interference*

What happens when two waves traveling through the same medium encounter one another? In general, we apply the principle of superposition to determine the net displacement of each point in the medium.

**The principle of superposition:** The net displacement of any point in a medium is the sum of the displacements at that point due to each of the individual waves.

Figure 21.11 shows what happens when two pulses moving in opposite directions along a stretched string meet one another. Both pulses displace the string upward as they travel, so when the peaks of the pulses coincide, the net displacement of the string at that point is equal to the sum of the amplitudes of the pulses. This is known as **constructive interference** - the displacements of the individual waves are in the same direction, and thus add together. An interesting implication of the principle of superposition is that the waves do not change one another's shape as they pass through one another. After passing through, they move away unchanged.

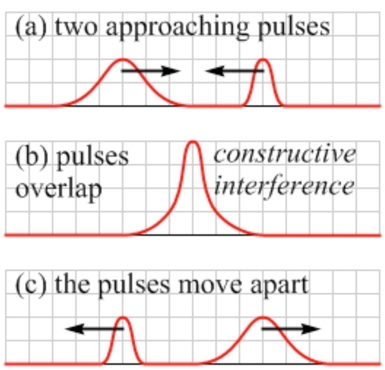


**Figure 21.11**: The successive images show two pulses moving in opposite directions along a string. At points where the pulses overlap, the net displacement of the string is the sum of the displacements due to the individual waves. In this case, (b) shows **constructive interference**, because the displacements of both pulses are in the same direction.

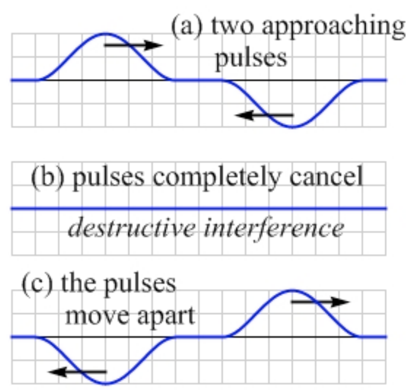


**Figure 21.12**: The successive images show two pulses, which are mirror images of one another, moving in opposite directions along a string. In this case, (b) shows completely **destructive interference**, with the pulses exactly canceling one another at the instant they overlap completely.

In Figure 21.12, we see what happens when two pulses that have opposite displacements meet one another while traveling along a stretched string. In this situation, because one pulse is a mirror image of the other, when the pulses coincide the net displacement of the string is zero everywhere, just for an instant. This is known as **destructive** interference, where the displacements of the individual waves are in opposite directions, and thus fully or partly cancel. Once again, after passing through one another, they move away as if they had never met.

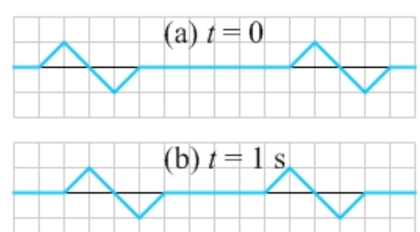


**Figure 21.13**: Two pulses, one traveling left and one traveling right, on a stretched string. The profile of the string is shown at (a) $t = 0$ and (b) $t = 1.0$ s.

**EXPLORATION 21.7 – A process for adding two pulses**

Figure 21.13 shows two pulses traveling along a string. The string is shown at two separate times, $t = 0$, and $t = 1.0$ s. We want to know what the string looks like at $t = 4.0$ s, $t = 5.0$ s, and $t = 6.0$ s.

**Step 1 – *Based on the two pictures in Figure 21.13, determine where each of the two pulses will be at t = 4.0 s. Sketch three diagrams, one above the other. First, sketch a diagram showing the position of the rightward-moving pulse. Second, sketch a diagram of the leftward-moving pulse. Use those two diagrams to determine where the two pulses overlap, and use superposition to draw the string as it looks with both pulses on it.*** From Figure 21.13, we can see that the pulses travel along the string with a speed of 1 grid unit per second. After three more seconds have passed, the right-going pulse will be three units to the right, and the left-going pulse will be three units to the left, as shown in Figure 21.14. The pulses destructively interfere in the region of overlap, which is shaded in Figure 21.14.

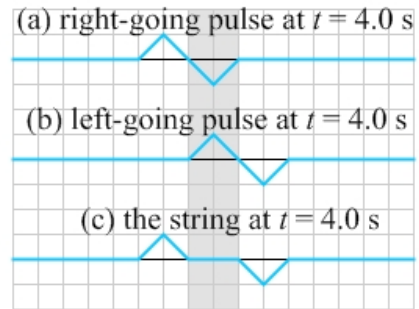


**Figure 21.14**: The two separate pulses, in (a) and (b), and the profile of the string (c), at $t$ = 4.0 s. The region where the pulses overlap is shaded.

**Step 2 – *Repeat the process outlined in step 1 above, but at t = 5.0 s.*** Because another second has passed, we slide each pulse over by one unit. At $t$ = 5.0 s, the pulses completely overlap. Because they have identical profiles, the pulses constructively interfere, doubling the displacement at each point in the region of overlap, as shown in Figure 21.15.

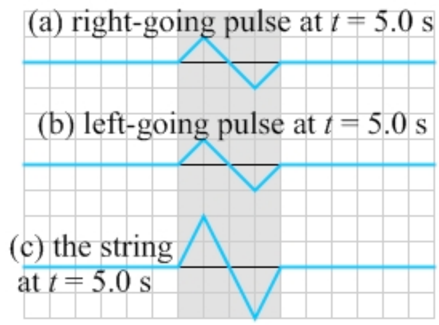


**Figure 21.15**: The two separate pulses, in (a) and (b), and the profile of the string (c), at $t$ = 5.0 s. The region where the pulses overlap is shaded.

**Step 3 – *Repeat the process outlined in step 1 above, but at t = 6.0 s.*** An additional second has passed, so we again slide each pulse over by one unit. At $t$ =6.0 s, the net result is the same as at $t$ = 4.0 s, with the two pulses simply swapping positions on the string, as shown in Figure 21.16.

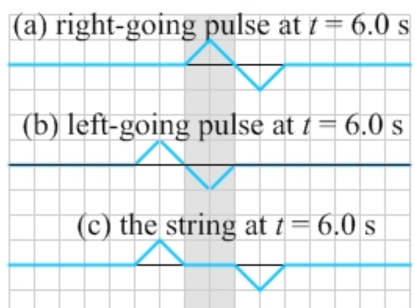


**Figure 21.16:** The two separate pulses, in (a) and (b), and the profile of the string (c), at t = 6.0 s. The region where the pulses overlap is shaded.

**Key idea**: When two waves meet, apply the principle of superposition. A useful method is to sketch each of the waves separately, and then add the displacements to find the net displacement in the region where the waves overlap. **Related End-of-Chapter Exercises: 1 – 4.**

**Interference in Two Dimensions**

When two sources emit identical waves, an interesting pattern is created near the sources because of the interference that takes place. The type of interference that takes place at a point depends on the **path-length difference**: the difference between the distance from one source to the point and the distance from the second source to the point. When the sources emit identical waves, any point that is equidistant from the two sources (that is, having a path-length difference of zero), experiences constructive interference. These are not the only places where constructive interference occurs – any point at which the path-length difference is an integral number of wavelengths also experiences constructive interference. Destructive interference, on the other hand, occurs at points that are an integral number of wavelengths, plus half a wavelength, farther from one source than the other. We will discuss these ideas in more detail in chapter 24.

***Essential Question 21.7***: In the picture of the string in Figure 21.12(b), the string is completely flat. In Figure 21.12(c), the two pulses re-emerge from the flat string. How is this possible? For instance, where is the energy, in (b), necessary to re-form the two pulses?