3.6.1.2: The Doppler Effect Simulation

This simulation looks at the Doppler effect for sound; the black circle is the source and the red circle is the receiver. The time is measured in centiseconds (10^{-2} s), distances are in meters. A similar effect occurs for light but in that case the source and receiver cannot travel faster than the wave speed (the speed of light).

Simulation Questions:

1. Click the play button to see a stationary source and receiver (Animation 1). Reset and use the pause and step buttons to verify that the period at the receiver (time elapsed from when one wave reaches the receiver until the next one reaches it) is 5.0×10^{-3} s. What is the frequency of this wave?
2. After there are several waves in the simulation pause it and use the mouse to find the wavelength (distance between two successive crests). What are the wavelength and speed of the wave (wavelength/period)?
3. Now look at Animation 2, where the receiver is moving. Use the step button above to find the period (time between crests) *as measured by the moving receiver* when it is on the right of the source (moving towards the source). What is the frequency at the receiver if it is moving towards the source?
4. When the receiver gets to the left of the source (moving away from the source) pause the simulation and measure the period. What is the frequency at the receiver if it is moving away from the source?
5. Now look at Animation 3 which shows the source moving but the receiver stationary. Again find the frequency while the source is on the left, moving towards the receiver and the frequency when it is on the right moving away.

Advanced Questions:

Animation 4 shows the effects of a moving source and a moving observer at the same time. The equation for the Doppler shift with both a moving source and observer is given by $f' = f(v \pm v_o)/(v \mp v_s)$ where f' is the received frequency, f is the original frequency, v is the speed of the wave, v_o is the speed of the observer and v_s is the speed of the source. The upper signs in the equation are used if either the observer or source is moving towards each other and the lower signs are used if the either object is moving away from the other (so if the observer is moving towards the source but the source is moving away from the observer the equation to use is $f' = f(v + v_o)/(v + v_s)$).

1. For the case of the moving receiver and stationary source ($v_s = 0$) use the original frequency you found in question one, the shifted frequency (f') you found in question three and the speed of sound you found in two to find the speed of the observer.
2. Animation 5 shows a source moving faster than the speed of the sound wave. In this case all of the wave crests arrive together forming a shock wave or "sonic boom". Why can this not happen in the case of light from a moving light source?
3. Electromagnetic waves will also undergo a Doppler shift except that the relative velocity between the source and observer can never be larger than the speed of light and the formula for calculating the shift is slightly different. For electromagnetic waves we have $f' = f((c+v)/(c-v))^{1/2}$ where v is the relative speed between the observer and source (positive if they are approaching and negative if they are moving away from each other) and c is the speed of light.
4. If the speed of the wave is known and the original and received frequencies are know the speed of the source or observer can be found. Explain how you could determine the speed of a car or thunderstorm by bouncing radio or microwaves off of them. (Police radar and thunderstorm tracking both use the Doppler Effect.)
5. If a car goes past with its radio blaring we easily hear the Doppler shift for sound as the car passes (the sound appears to shift from a pitch which is too high to one which is too low). (Note: We are talking about the change in pitch, *not* the change in volume.) But if a car goes past with its lights on we do not notice the Doppler shift for light (the color does not seem to shift towards the red frequencies). Explain why this is so. (Hint: Try plugging in some numbers for a car speed in the equation for the Doppler shift for light).
6. If an astronomer notices that the spectrum of colors coming from a star are all shifted towards the red end of the spectrum (the frequencies are lower than they should be) what can she conclude about the motion of the star relative to the earth? (This is one of the pieces of evidence that the universe is expanding; nearly all the stars and galaxies around us are moving away from us.)

Chapter Seven Summary

Waves (of all types) will: reflect (diffuse or specular) at the same angle when they hit a solid surface; bend if their speed changes (refraction); bend if they run into an object or opening that is near the same size as the wavelength (diffraction); change frequency (NOT loudness!) if the source or receiver are moving (Doppler shift). Two waves can add constructively or destructively to give a wave with larger amplitude (louder sound or brighter light) or sound cancellation, standing waves, beats, interference (colors on soap bubbles, moth wings, bird feathers).

Questions on Wave Behavior:

1. Give a definition of the law of reflection.
2. Do sound waves obey the law of reflection? Explain.
3. A police officer has a new sound gun that stuns the criminal. They can see their suspect who is around the corner, reflected in a mirror. Should she simply aim at the image of the target in the mirror? Explain.
4. Trucks sometimes have a sign on the back that says “If you can’t see me in my mirror, I can’t see you.” Explain the physics here.
5. Why is the image in a mirror reversed left to right but not top to bottom? (A drawing might help your explanation.)
6. Some storefront windows are angled so the bottom is further in and the top comes out towards the street. Explain how this would help reduce glare on a bright day. (A drawing might help your explanation.)
7. What is the difference between diffuse reflection and specular reflection?
8. Why are matte finishes for photos and books generally better than glossy finishes?
9. Why do sound studios often have the walls covered with egg carton shaped foam?
10. Why is it harder to see the road at night in the rain?
11. Give a definition of the law of refraction, explaining the difference between reflection and refraction.
12. How does refraction depend on the speed of a wave?
13. Give some examples of common, everyday objects that use refraction to operate.
14. Why are images blurry underwater if you don’t have goggles?
15. Why are images not blurry underwater if you are wearing goggles?
16. If a fish wore goggles to come above the surface, why would it want to have goggles filled with water?
17. If you place a glass test tube in water you can still see it but if you place it in soybean oil it disappears. What does this tell you about the speed of light in glass, water and soybean oil?
18. If you want to spear a fish under water from the shore should you aim below it, at it or above it? Explain.
19. If you want to zap a fish with a laser, should you aim below it, at it or above it? Explain.
20. Why does a pond or lake with very clear water look shallower than it really is? Explain using a diagram.
21. Suppose color X bends more when passing through glass than color Y. Which moves slower in the glass?
22. What is total internal reflection? When does it occur?
23. What modern devices depends on total internal reflection?
24. On a windy day, why can you hear someone clearly if they are downwind but can’t hear them as well if they are upwind?
25. Why is it difficult to hear someone on the other side of a lake during the day when the air above the lake is cool but very easy to hear voices at night when the air above the lake is warmer than air higher up? (Hint: Sound travels faster in warmer air.)
26. The term ‘heat lightning’ is sometimes used to describe lightning that we can see off at a distance but not hear. Why don’t we hear it like ordinary lightning? (Hint: Think about the previous question.)
27. What is dispersion and what causes it? Give an example.
28. What is constructive and destructive interference? When does each occur?
29. Explain how does path difference cause constructive and destructive interference?
30. Explain how the phenomena of beats occurs.
31. Why do some bird feathers appear to be iridescent, changing color when viewed from different angles?
32. What causes the different colors on a CD disk?
33. What causes the different colors on a soap bubble?
34. Suppose you are standing directly in front of a pair of stereo speakers. Why would you expect the sound not to be quite as loud if you move slightly to the left or right?
35. What is diffraction? Give some examples.
36. Under what circumstances do you expect to see the effects of diffraction?
37. Why can you hear sound from the other room, even when you cannot see into the room?
38. Why does light not bend when it passes through a doorway but sound does?
39. What is scattering?
40. Why is the sky blue?
41. What is the Doppler effect?

42. A friend hears an ambulance go by and says this is an example of the Doppler effect because the sound got louder and then softer. Correct your friend’s mistaken definition of the Doppler effect.
43. Give an example of the Doppler effect for light and one for sound.
44. Does the Doppler shift depend on whether the source or the receiver is moving?
45. Does the speed of the wave change when there is a Doppler shift? Explain.
46. We can easily hear the Doppler shift of a car passing by but we do not notice the Doppler shift of light from its headlamps. Why is that?
47. Originally radar was just used to find the distance to a plane or thundercloud by measuring how long it took for the signal to return. What additional information does measuring the Doppler effect provide?
48. What is one piece of information that tells us the universe is expanding?
