4.1: Doppler Effect

Tutorial 4.1: The Doppler Effect

If either the source or the receiver of a wave are in motion the apparent wavelength and frequency of the received wave change. This is apparent shift in frequency of a moving source or observer is called the **Doppler Effect**. The speed of the wave is *not* affected by the motion of the source or receiver and neither is the amplitude. 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. The speed of sound is 345 m/s. A similar effect occurs for light (speed $= 3 \times 10^8 \text{ m/s}$) but in that case the source and receiver cannot travel faster than the wave speed (the speed of light).

Doppler Effect

Questions:

Exercise 4.1.1

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 $0.5 \times 10^{-2} \text{ s}$. What is the frequency of this wave?

Exercise 4.1.2

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)?

Exercise 4.1.3

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?

Exercise 4.1.4

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?

Exercise 4.1.5

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.

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 $f' = f(v \pm v_0)/(v \mp v_s)$ where f' is the received frequency, f is the original frequency, v is the speed of the wave, v_0 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 $f' = f(v+v_0)/(v+v_s)$).

Exercise 4.1.6

For the case of the moving receiver and stationary source ($v_s = 0$) use the original frequency you found in question 3.10.1, the shifted frequency (f') you found in question 3.10.3 and the speed of sound you found in 3.10.2 to find the speed of the observer.

Exercise 4.1.7

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?

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.

Exercise 4.1.8

As you can see from the question 3.10.6, 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.)

Exercise 4.1.9

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).

Exercise 4.1.10

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.)