Laboratory 9: Waves

Waves occur in various branches of physics and are important for describing certain optical phenomena. The aim of this exercise is to introduce you to the basic concepts used to describe waves.

In order to illustrated the basic ideas, consider a stretched horizontal string. If one end of the string is repeatedly moved up and down in the appropriate way, then a pattern consisting of crests and troughs will propagate along the length of the string. Snapshots of segments of the string at two instants might appear as illustrated in Fig. 1.

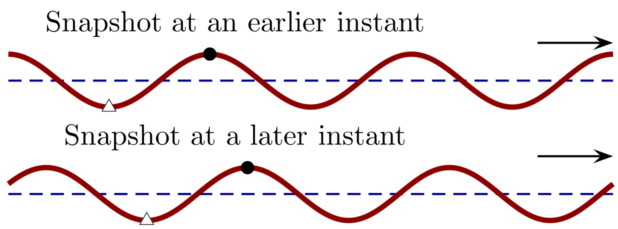


Figure 1: Wave traveling rightwards along a string. The horizontal dashed line indicates the appearance of a segment of the string in the absence of any wave. The solid dot labels one particular crest at the two instants. The hollow triangle labels one trough at the two instants.

The spatial aspects of a wave can be described using a snapshot of the wave at one instant. Figure 2 illustrates this.

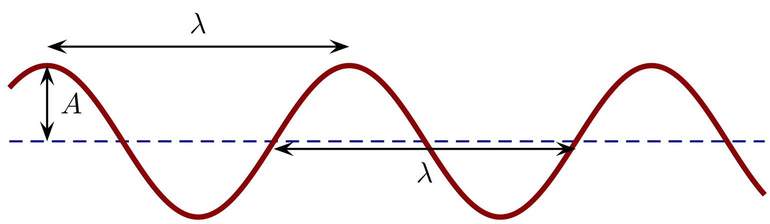


Figure 2: Snapshot of a wave at one instant, indicating the wavelength, λ and amplitude, A.

The two quantities, each illustrated in Fig. 2, that describe the spatial appearance of the wave are:

1. **Amplitude:** The amplitude, A, is the maximum displacement of the string from the horizontal equilibrium and has units that depend on the nature of the wave. This describes the vertical extent of the wave. The amplitude is usually related to the energy transported by the wave. For sound waves the amplitude describes the intensity of the sound (how loud it is) and for light waves the intensity of the light (how bright it is).

2. **Wavelength:** The wavelength, λ (the Greek letter "lambda"), is the horizontal distance between two *successive* points that appear in the same location on the pattern. For example, the distance from one crest to another equals the wavelength. This has units of meters and describes the horizontal extent of the wave pattern.

The two quantities that describe the evolution of the disturbance as the pattern passes are:

1. **Period:** The period, T, is the time taken between the arrival of successive crests at one location as the wave travels past that location. This is measured in seconds. An example is illustrated in Fig. 3; in this case the period would be $3.7\,\mathrm{s}$.

2. **Frequency:** The frequency is

$$f = \frac{1}{T}$$

where T is the period. The units of frequency are Hertz (Hz). This is the number of crests that pass any given horizontal point every second. For sound waves the frequency corresponds to the pitch of the sound with the higher frequencies corresponding to higher notes. For light the frequency corresponds to the color of the light with red having a lower frequency than blue.

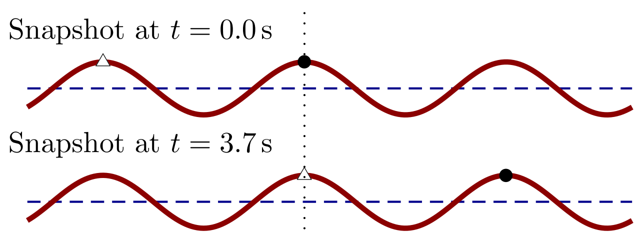


Figure 3: Wave traveling rightwards along a string. Two successive crests pass the vertical dotted line. The time from one to the next is $3.7\,\mathrm{s}$.

Finally the wave speed is the speed with which the pattern propagates (to left or right). If one followed the horizontal progress of one crest and observed that it travels horizontally through a distance Δx in time Δt, then the wave speed is

$$v = \frac{\Delta x}{\Delta t}.$$

The wave speed depends on the characteristics of medium (e.g. string) that hosts the wave but, for all waves,

$$v = \lambda f$$

which is a crucial result for wave physics.

1 Animation: Water and Sound Waves

The basic nature and ideas of waves can be illustrated with the PhET animation, Waves Intro, which can be found at:

https://phet.colorado.edu/en/simulation/waves-intro

This should be able to run in an internet browser on most platforms.

a) Open the animation and click the Water option.

b) Waves can be produced by clicking the green button on the faucet. Click this button. You should see a picture of the water waves as viewed from above. The bright areas indicate crests and the dark indicate troughs. Pause the animation. Consider a single crest. Note that it occupies an extended region of space. What is the shape of the crest (e.g. horizontal straight line, vertical straight line, ...)?

c) The animation allows a side view. Click Side View and run the animation. In which direction does the wave appear to propagate?

d) Return to the Top View. Using the slider on the right, decrease the frequency. Describe what happens to the separation between successive crests (increases, decreases or stays constant). Describe what happens to the speed of the speed of the wave changes (increases, decreases or stays constant).

e) Click the Sound option. This will display a speaker which can be activated by pressing the green button. Ensure that the frequency slider is at the middle setting. Click the green button and allow the sound waves to fill the visible box. Pause the animation. Using the tape measure icon (top right box), measure the wavelength of the wave and enter it below.

f) Drag the timer (top right box) into a location near to the wave. Observe the crests of the wave passing one location and determine the time between the arrival of successive crests at this location. This is the period, T, and is given in milliseconds. Use this to determine the frequency of the wave and enter it below.

g) Use the wavelength and frequency to determine the wave speed and enter it below.

h) Using the slider, decrease the frequency to about a quarter of the maximum. Determine the wavelength and frequency of this wave and use the results to determine the wave speed.

i) Are the two calculated wave speeds more or less similar?

2 Animation: Waves on String

Waves in two dimensions, such as sound and water waves contain some complications that are absent from waves that propagate along a one-dimensional medium such as a string. These can be illustrated by the PhET animation, Waves on a String, which can be found at:

https://phet.colorado.edu/en/simulation/wave-on-a-string

This should be able to run in an internet browser on most platforms.

a) Open the animation, which will display a string, to which many colored beads are attached.

b) In the top right control panel, check No End. The right end of the string should pass through an open window (the animation imagines that it continues endlessly beyond the window).

c) In the bottom control panel adjust the Damping slider so that the damping is zero. This removes friction and air resistance.

d) In the bottom control panel adjust the Tension slider to the middle setting.

e) In the bottom control panel select Rulers and Timer.

f) The frequency slider can be set to various values. For each value one can determine the wavelength, period, frequency and the wave speed. The wavelength can be measured by pausing the animation and using the ruler. The period can be measured by using the timer to measure the time between arrival of successive crests at the window. The frequency and be calculated from $f = 1/T$ and the wave speed can be determined by timing how long, Δt it takes for a crest to travel a given distance, Δx, and using $v = \Delta x/\Delta t$. For each of the following frequency slider settings, determine the various quantities and fill out the table.

Freq slider setting	Wavelength	Period	Wave Speed $v = \Delta x/\Delta t$	λf
0.60 Hz				
0.80 Hz				
1.00 Hz				
1.20 Hz				

g) In each case, is the wave speed calculated by $v = \Delta x/\Delta t$ approximately equal to λf?

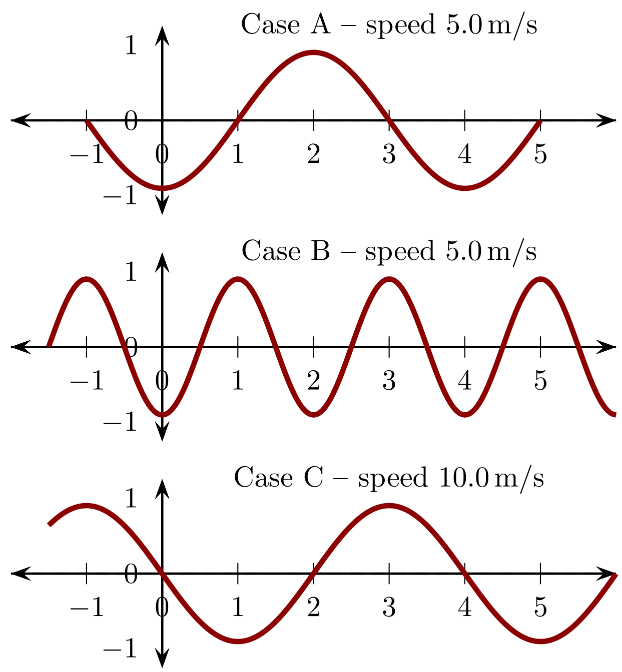
h) Does the wave speed depend on the frequency of the waves? Explain your answer.

i) Keeping the frequency slider fixed, adjust the amplitude. Does this change wave speed?

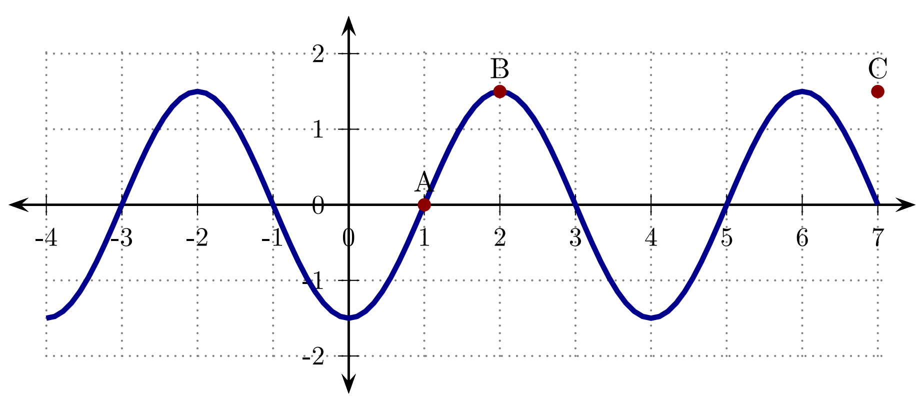
3 Exercises

Complete the following exercises.

a) Various waves on strings are as illustrated. The wave speeds are provided for each case. The units of the axes are meters. Rank the waves in order of increasing wavelength. Rank the waves in order of increasing frequency. Explain your answers.



b) A snapshot of a segment of a wave on a string at a particular instant is illustrated. The distances are measured in meters. It is observed that the time between the arrival of successive crests at location A is 0.250 s.



i) Determine the frequency of the wave.

ii) Determine the wavelength and speed of the wave.

iii) Determine how long it will take the crest labeled B to reach the point C.

iv) Using the graph above, sketch the wave at an instant 0.0625 s after that illustrated above.