Lab 14: Standing Waves

Objectives:

- To understand superposition of waves
- To understand how a standing wave is created
- To understand relationships between physical parameters such as tension and length of string and wave features such as velocity, wavelength and frequency for standing waves
- To understand the relationship between the number of antinodes and frequency and tension.

Equipment:

- Standing wave setup
- Balance
- Meter stick
- 75g and 150g masses

A mechanical wave pulse is a disturbance that travels through a medium causing a temporary displacement of the medium. If the pulse is repeated, then the traveling disturbance is called a waveform, or more simply a wave.

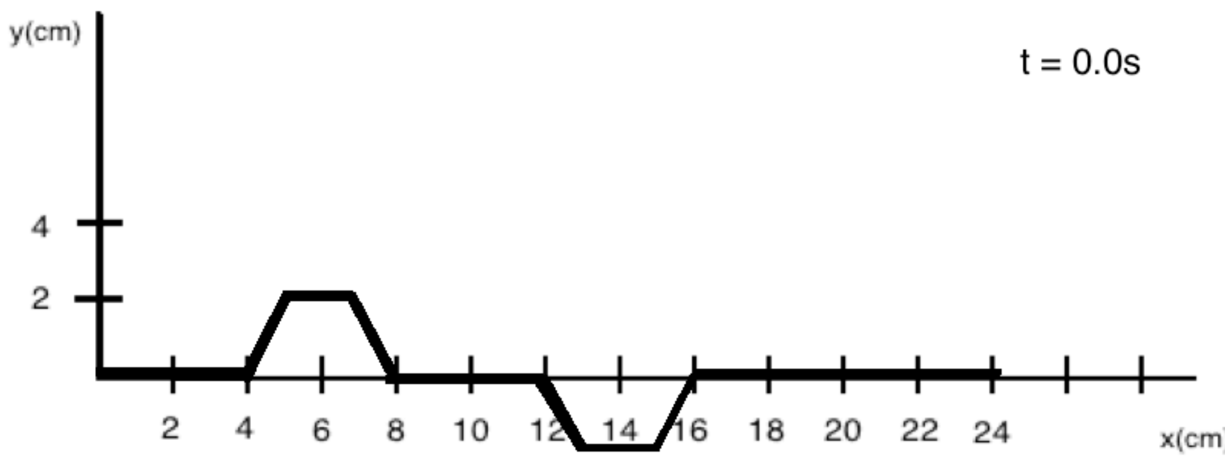
Waveforms can have variety of shapes. The most simple form is sinusoidal, which is the form we will examine here. There are two types of mechanical waves, longitudinal and transverse. In a longitudinal wave, the medium is displaced along the line of propagation. Sound waves and certain types of seismic waves are examples of this type of wave. Transverse waves are waves in which the displacement is perpendicular to the direction of propagation. Water waves and waves on a guitar string are examples of transverse waves.

There are several properties all waves share, but they are easiest to see in sinusoidal waves. The *amplitude* is the maximum displacement of the medium from equilibrium. For a transverse wave, the amplitude above the equilibrium is called a *crest*, while the amplitude below the equilibrium is called a *trough*. The *wavelength* (λ) is simply the distance between two points on the waveform before the pattern begins to repeat. For example, the distance from one trough to the next would be one wavelength, while the distance from where the pattern crosses the equilibrium point to the next is not. The *period* (T) is the time one wavelength takes to travel past a certain point. The period is usually, but not always, measured in seconds. The inverse of the period is the *frequency* (f), or how many cycles (wavelengths) pass a given point in a set period of time, usually one second. The speed (v) of the wave is given by $v = f\lambda$.

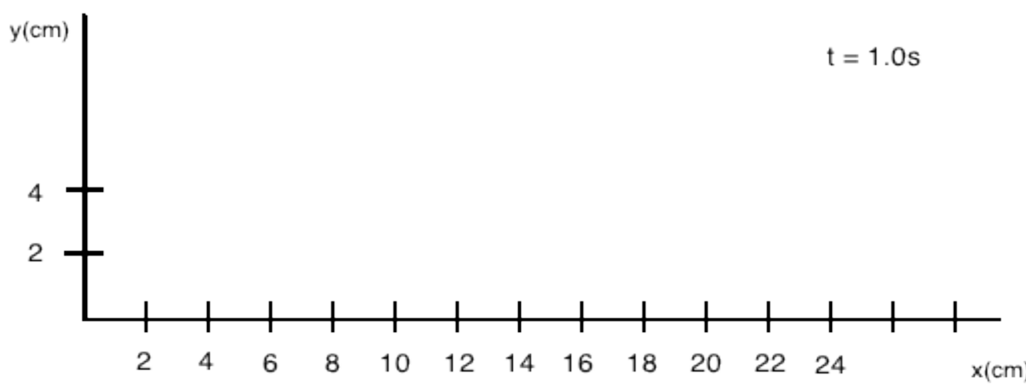
Guitar strings provide one of the most common sources of what are known as standing waves. A standing wave can be thought of as two waves of equal amplitude and frequency traveling in opposite directions along a string simultaneously. Where a crest from one wave meets a trough from another wave, they cancel each other out (*destructive interference*), and there is no displacement of the string. Where trough meets trough (or crest meets crest), the waves add (*constructive interference*), producing a displacement. Places at which the string isn't displaced, are called *nodes* and the locations of maximum displacement are called *antinodes*.

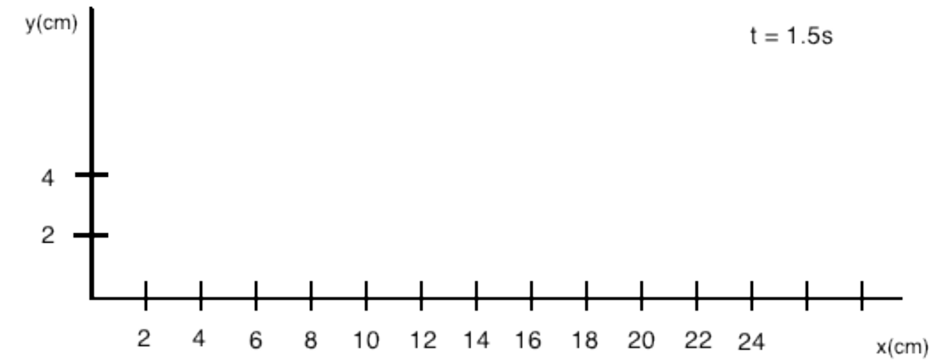
Exploration 1 Superposition

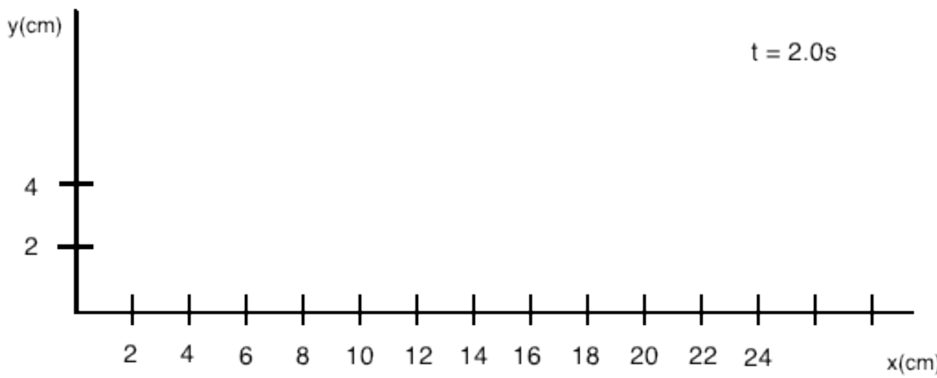
Exploration 1.1 Consider, not a wave, but just two pulses moving down a string in opposite directions, pulse A and pulse B, as in the picture below. Both pulses have a speed 2.00cm/s. The pulses have the same height. The picture shows the pulses at time t = 0s. Sketch the shape of the string at the following times: 1s, 1.5s, 2.0s, 2.5s, and 3s by drawing each wave and then the superposition of the two waves. If you have different colors draw each wave in a different color and the superposition in a third color. The superposition is what you would actually see on the string. Sketch the pulses for each time on the graphs below and on the next page. Take your time and do it rigorously, getting the positions and amplitudes numerically correct.

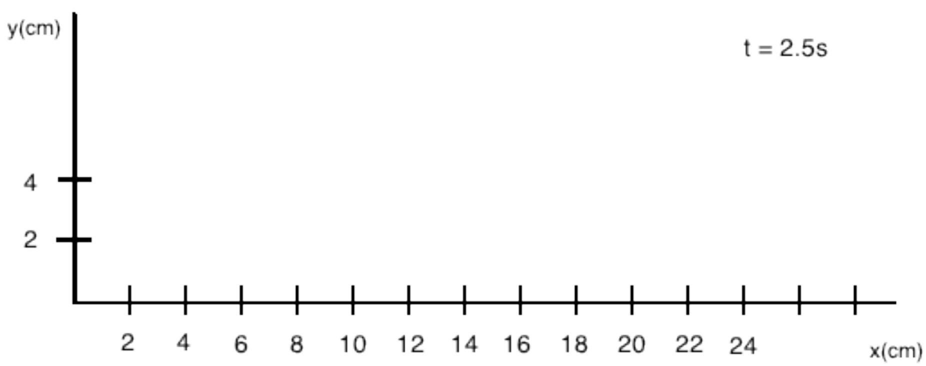


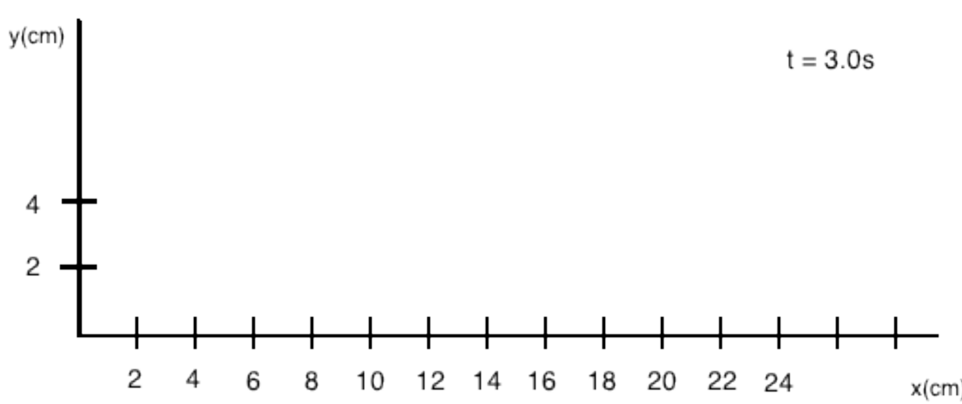
(from Raymond A. Serway and Robert J. Beichner, *Physics for Scientist and Engineers 5[Th] Edition*, Harcourt College Publishers, 2000.)




y(cm)
t = 1.5s
4
2
2 4 6 8 10 12 14 16 18 20 22 24
x(cm)

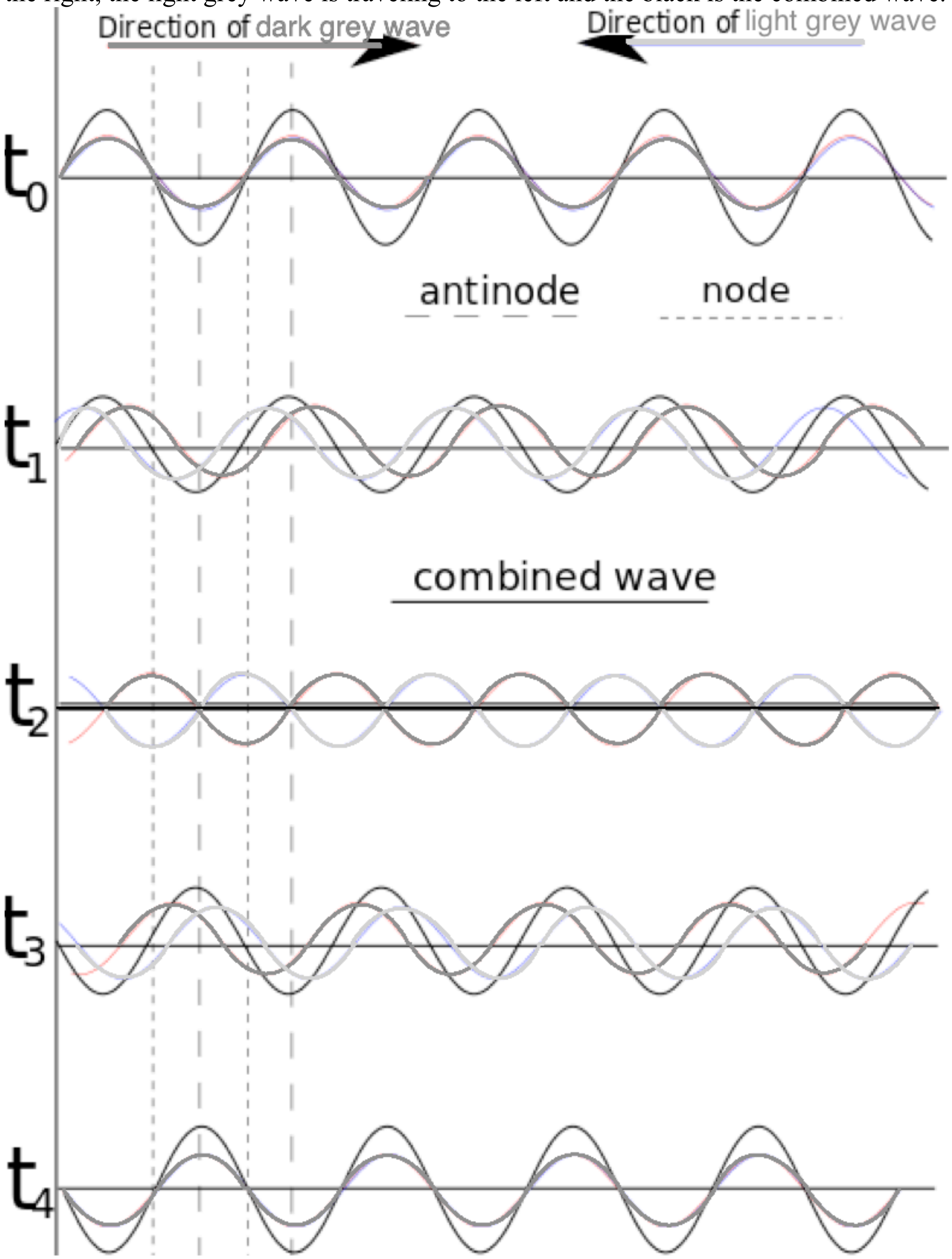

y(cm)
t = 2.0s
4
2
2 4 6 8 10 12 14 16 18 20 22 24
x(cm)


y(cm)
t = 2.5s
4
2
2 4 6 8 10 12 14 16 18 20 22 24
x(cm)


y(cm)
t = 3.0s
4
2
2 4 6 8 10 12 14 16 18 20 22 24
x(cm)

Exploration 2 Standing waves

A standing wave is a little harder to draw. We will look at a picture of two waves of the same amplitude and frequency traveling in opposite directions. The dark grey wave is traveling to the right, the light grey wave is traveling to the left and the black is the combined wave.



(from http://en.wikipedia.org/wiki/Standing_wave, 06/12/2014)

Exploration 3 Observation of standing waves

Exploration 3.1 One way to set up a standing wave is to reflect a wave from a fixed endpoint. Examine the setup at your table and use the oscillator to set up a standing wave. There is not really a node at the point of the oscillator, but you can still set up a standing wave by using the fine adjustment on the frequency generator. Try to create standing waves with one, two and three antinodes.

Exploration 3.2.a How is the length of the string related to the number of antinodes and the wavelength? Write this as an equation with L = length of string, n = number of antinodes and λ = the wavelength.

Check your equation with your TA before you continue.

Exploration 3.2.b The frequency at which $n = 1$ is known as the fundamental frequency. If a string 1.5 m long vibrated at the fundamental frequency, what would be the wavelength of the wave? Answer in the space below and explain your reasoning.

Exploration 3.3 How is the number of nodes related to the number of antinodes? Explain.

Exploration 4 String Tension

The speed of a wave on string is a function of the tension of the string and is given by

$$v = \sqrt{\frac{T}{\rho}}$$

where T is the tension and ρ is the mass density (mass per unit length) of the string.

Measure the length and mass of the sample string and calculate the mass density of the string. Record the result below.

Mass density ________________________

Investigation 1 Frequency of standing waves at constant tension

In the first experimental setup you will be using, the tension in the string will remain constant and you will vary the frequency to establish various standing waves. Collect the data in the following table. Use a mass of 75 g on the hanger.

Number of Antinodes	Frequency (Hz)
1	
2	
3	
4	
5	
6	

Investigation 2 Changing the tension

Investigation 2.1 Suppose you were to use mass of 150 g on the hanger, instead of a mass of 75g. What would change?

Predict whether the following factors would change and if you can determine how they change (such as a factor of 2, or increase by 5, etc.) record that also:

	Change? (Y or N)	How it changes (numerically)
tension		
velocity		
lowest frequency		
longest wavelength		

Repeat the data with a mass of 150g.

Number of Antinodes	Frequency (Hz)
1	
2	
3	
4	
5	
6	

Do the data support your predictions?

Investigation 2.2

Investigation 2.2.a If you were to graph the frequency vs. the number of antinodes for each set of data, what do expect the graph to look like? Explain.

Investigation 2.2.b Using Excel, plot the data for each trial.

Investigation 2.2.c Can you determine the velocity of the wave or the tension in the string from your graphs? Explain and determine those quantities from your graph.

Investigation 2.2.d If you have a different way to determine the tension in the string, calculate it a different way and compare. Do you need to consider uncertainty? Explain.