Weighted Monochord Lab Activity

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Abstract

This laboratory exercise, aimed at a high-school audience, will teach students some principles behind the vibration of strings, and allow them to test hypotheses based thereupon. Experiments will be conducted using a simple monochord set-up.

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1 Introduction

In this lab, you will learn the physical principles governing the fundamental frequency of vibration of a string fixed at both ends, also known as a *monochord*. This will involve review of equations related to wave propagation, and the modes of resonance in a monochord with given physical characteristics. The lab exercise for this module will involve making and testing predictions regarding the fundamental frequency of string vibration in the monochord apparatus.

2 Objectives

- Understand certain principles underlying string vibration.
- Make and test hypotheses concerning properties of string vibration.

3 Theory

A monochord, or a string fixed rigidly at both ends, will exhibit various *modes of vibration* simultaneously. Each of these modes will have a *wavelength* associated with it. In vibrating strings, as well as other situations involving wave propagation, wavelength is related to frequency by the following formula:

$$v = f\lambda, \tag{1}$$

where v is the velocity of propagation (this is typically constant for a given wave propagation medium) (in meters per second), λ is the wavelength (in meters), and f (in Hertz) is the frequency. For a constant wave velocity, it is important to note that this formula implies an *inverse relationship* between wavelength and frequency.

In a vibrating string held taught with a given tension T (in newtons), and with a linear mass density μ (in kilograms per meter), the velocity of propagation v is given by

$$v = \sqrt{\frac{T}{\mu}}. \tag{2}$$

For more information on these formulas, see Wikipedia's page on string vibration[1].

Finally, in a monochord of length L (in meters), it turns out that there are infinitely many possible modes. If we let $n = 1, 2, ...$ be the mode number, each mode will have a certain frequency $f(n) = nf_0$, and a corresponding wavelength, λ_n. As a consequence, all modes must obey the following:

$$L = \frac{n\lambda_n}{2}. \tag{3}$$

In other words, for every mode, the monochord length must be a multiple of half of the mode's wavelength.

[1] http://en.wikipedia.org/wiki/Vibrating_string

3.1 Fundamental Frequency of Vibration

Using the formulas above, we can show that the fundamental frequency of a string's vibration (defined as the lowest frequency mode, f_0) may, thus, be determined by the following formula:

$$f_0 = \frac{\sqrt{\frac{T}{\mu}}}{2L}. \tag{4}$$

4 Hypothesis

4.1 Monochord Parameters

In this lab, the monochord you will deal with will have the following parameters:

- The string used is a guitar A-string, made by D'Addario, Phosphor Bronze series, model PB045.
- The diameter of the string is 0.045".
- The linear mass density of the string is 0.0004175 pounds per inch.
- The string will be stretch over a length of approximately 25.25".
- Tension will be applied to the string using a hanging weight of 7.5 pounds.

Your task for this section is to formulate the following hypothesis: at which fundamental frequency do you predict the string will vibrate? To form this hypothesis, you may have to convert the above monochord parameters from imperial to metric units.

5 Procedure

1. First, download the Pd patch for this lab[2]. Open the Pd patch in Windows by double-clicking on the file you downloaded.
2. Your lab instructor will supply you with the weighted monochord apparatus, a sample of which is shown in Figure 1. Ensure that the string stretches smoothly over the monochord sensor, and does not bunch up around the monochord edge when the weight is suspended from the string's end, and shown in Figure 2. It may be helpful to have one lab partner hold the monochord, and the other partner make measurements.
3. Connect the monochord sensor to the audio input on the computer on which the Pd patch is running.
4. Under the `Media` menu in Pd, select `audio ON`. This will begin the recording of audio.
5. Have one lab partner gently pluck the string, while the other partner holds the apparatus. When you see a roughly periodic waveform, click `Pause Display`. You may click `Begin Display` to restart real-time waveform viewing. A sample of the paused plot you may obtain is shown in Fig. 3.

[2] http://ccrma.stanford.edu/ jos/weighted_mono/weighted_mono.pd

6. Finally, using the x-axis of the paused plot, measure the approximate distance between either peaks or troughs of the waveform. This will serve as an estimate of the period of the waveform. From this value, compute the fundamental frequency of string vibration (see part 3 of the monochord lab assignment to learn about the relationship between the period and the fundamental frequency). How does this compare with the fundamental frequency you predicted in the previous section?

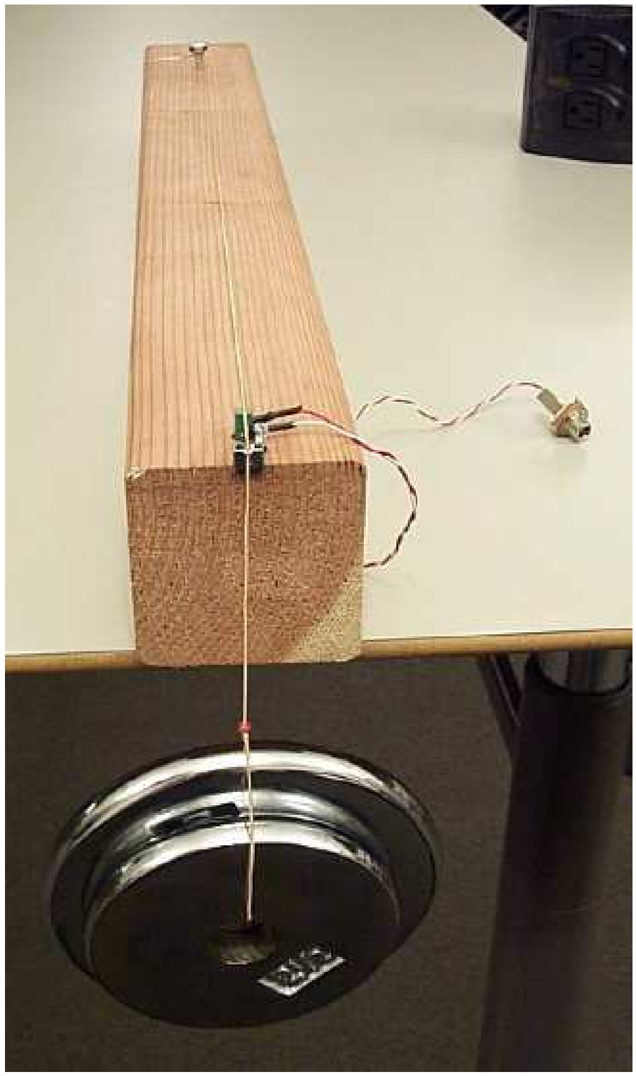

Figure 1: Photograph of the weighted monochord apparatus.

Figure 2: Photograph showing the weighted end of the apparatus.

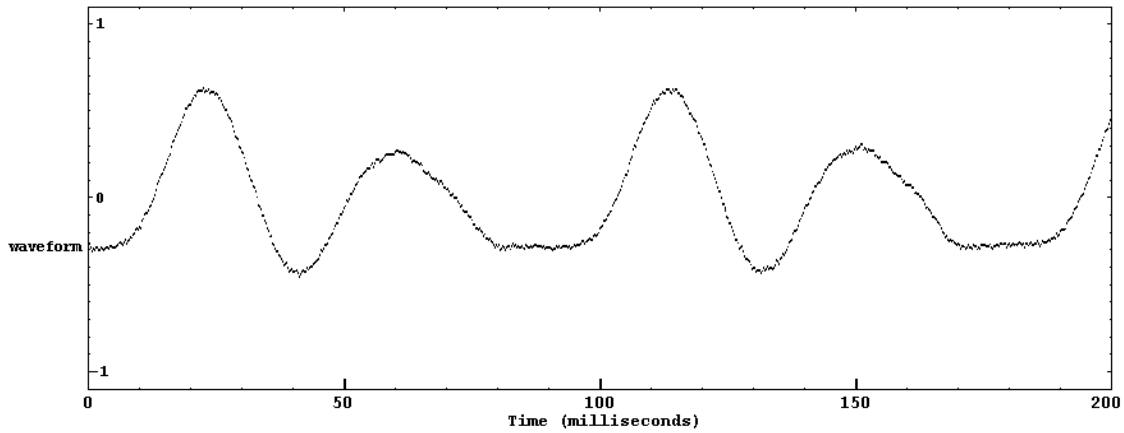

Figure 3: Pd patch for this lab activity, showing a few cycles of the waveform obtained from a vibrating string.

6 To Explore Further

See the monochord lab activity[3] for further explorations into the physics and acoustics of vibrating strings.

See also the demonstration of "standing waves" at `practicalphysics.org`[4].

[3] http://ccrma.stanford.edu/ jos/lab_inst/

[4] http://www.practicalphysics.org/go/Experiment_130.html