**Lauren Pelayo**

**Thomas Lindholm**

**Alex Lundin**

PHYS 2125.104.603

TA: Mathew Fong

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**Lab 8: Oscillations**

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6. **Abstract**

The purpose of this lab is to determine the mass density of the string the wave is propagated in from graphs, to study how harmonic number and tension affect frequency, and to compare the velocities found from using two different methods of calculation. A sine wave generator was used to adjust amp

litude and frequency to achieve the desired harmonic number. A string vibrator with power supply was used create waves by vibrating the string. The percent differences found between and range from to

We also investigated the properties of simple harmonic oscillator by comparing our experimental values for angular frequency and periods with our theoretical values. A block and a rod were used to show how inertia and affect the period of a physical pendulum. Our percent error for angular frequency was as low as 0.6210% and as high as 39.20%. Another purpose of the lab is to measure conservation of energy. This experiment was close to showing conservation of energy as we have received an average

rate of kinetic energy loss of -0.0628 J/s and an average rate of potential energy gain of 0.01128 J/s.

**2) Theory**

Simple Harmonic Motion

Simple harmonic motion is typically described by the motion of a mass on a spring when it is subject to the elastic restoring force that is proportional to the displacement. The frequency of a simple harmonic motion is determined by the mass m and the stiffness of the spring expressed in terms of a spring constant k. The force exerted by a spring is represented bythe equation.

where k is the spring constant, and x is the displacement of the spring. According to Newton’s Law, we can also write the equation in the form of

Since the acceleration of the system is only in the x direction, Then we would have the following differential equation,

with a solution of

where A is the amplitude of oscillation and is the angular frequency. With Logger Pro, we can find the angular frequency of spring oscillations. From there, we can use the angular frequency obtained to calculate the spring constant given by the following equation

Don’t forget that there is energy involved during spring oscillations. There is elastic potential energy current in the system and the equation for elastic potential energy at any time t is given by

And the system’s kinetic energy is

The maximum potential energy occurs when the spring is displaced its maximum amount, which is the amplitude A. At this point, the kinetic energy is zero. The expression for maximum potential energy is

The spring will have its maximum kinetic energy at the point where its potential energy is zero and because mechanical energy is conserved in simple harmonic motion, we know that So, the expression to determine the maximum kinetic energy is

In this portion of the experiment, different masses are hung by a string of negligible mass to determine the frequency of spring oscillations, spring constant k, the amplitudes and velocities of spring oscillations by compressing the spring and letting it execute five full oscillations. With Logger Pro, we obtain a sine wave function and from the graph, we can determine the angular frequency, amplitude of spring oscillations, the maximum velocity at its maximum displacement, and the time it takes to complete four full oscillations. Because mechanical energy is conserved, we expect the elastic potential energy and maximum kinetic energy to be the same.

Pendulums

There are two types of pendulums that we studied in experiment – simple pendulums and physical pendulums.

A simple is one that can be considered to be a point mass hanging from a string of negligible mass. The period T is the time the pendulum takes to make one full “there-and-back” swing. The formula for period is

where l is the length of the pendulum. Notice that the period does not depend on the mass.

Strings and rods are not truly massless, and when an extended body pivots about some axis, that is called physical pendulum. The inertia I of a physical pendulum depends on the geometry of the object and the axis of rotation. The expression for the period of a physical pendulum is

where h is the distance from the object’s center of mass of the axis of rotation.

In this section of the experiment, we determine the periods of a rod pendulum by pivoting the rod at different lengths – long and short. For the rod pendulum, we study not only whether lengths affect periods but also mass. Two trials are done for each length– one with 100 grams and another without 100 grams. As for the wooden pendulum, we oscillate this object about axes perpendicular to its largest face to determine the period for one full oscillation.

String Vibrations and Standing Waves

A standing wave is a vibration of a system in which some particular points remains fixed in position over time. These particular points are called nodes. We can describe standing waves by how many nodes are present, including the endpoints. If there are two nodes, we get half a wavelength. If we get three nodes, we get one full wavelength. We can also describe standing waves by how many half- wavelengths the wave has. This is called the harmonic number. The harmonic number is one less than the number of nodes. The expression for the harmonic number in terms of the vibrating length and wavelength is

To describe the speed at which the wave is traveling, we can use the following expression.

where f is the frequency. We can express the frequency with the formula shown below.

There are two ways a standing wave can be produced. The first is by propagating a wave in a medium, such as a string .The second is described by the principle of superposition. It explains how the incident and reflected waves combine to produce a standing wave, provided they have the same propagation speed, wavelength, and amplitude.

We can use the following equation to study these two waves that form a standing wave.

The velocity of a traveling wave can also be described in terms tension and the mass densityof a string.

In the lab, we have produced standing waves with two strings of different gauge cords. The goal is to achieve several different harmonic numbers by altering the frequency and amplitude of the wave. We have observed the relationship between frequency and tension, and frequency and harmonic number. From our formula for a wave’swe expect to see that an increase in tension of a string causes an increase in the velocity that the wave is traveling on the string. We also expectto be equal to as they are just two different methods of calculations.

**3) Data**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  |  |  |  | % error |  |
| 200 | 0.2299 | 9.062 | 9.327 | 2.841 | 18.88 |
| 250 | 0.2799 | 8.106 | 8.453 | 4.105 | 18.39 |
| 300 | 0.3299 | 7.658 | 7.786 | 1.644 | 19.35 |
| 350 | 0.3799 | 7.177 | 7.256 | 1.089 | 19.57 |

Table 1: Data table for frequency of spring oscillations and spring constant

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  |  |  |  |  |  |
| 200 | 0.1080 | 0.1630 | 0.0830 | 0.0620 | 2.75 |
| 250 | 0.1430 | 0.2310 | 0.1240 | 0.0900 | 3.00 |
| 300 | 0.2090 | 0.1980 | 0.1940 | 0.2340 | 3.30 |
| 350 | 0.2580 | 0.2410 | 0.2410 | 0.3500 | 3.60 |

Table 2: Data table for amplitudes and velocities of spring oscillations

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  |  |  |  |  | % error |
| with 100g | 0.4130 | 6.3 | 1.260 | 1.230 | 2.439 |
| w/o 100g | 0.3780 | 5.7 | 1.140 | 1.234 | 7.618 |
|  |  |  |  |  | % error |
| with 100g | 0.2330 | 4.9 | 0.980 | 0.9688 | 1.156 |
| w/o 100g | 0.2145 | 5.2 | 1.040 | 0.9296 | 11.88 |

Table 3: Data table for periods of rod pendulum

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Hole # |  |  |  |  |  | % error |
| 1 | 3.85 | 0.77 | 0.0525 | 0.04601 | 1.038 | 25.83 |
| 2 | 4.75 | 0.95 | 0.0280 | 0.03955 | 1.318 | 27.92 |
| 3 | 20 | 4 | 0 | 0.03698 | N/A | N/A |
| 4 | 4.05 | 1.76 | 0.0425 | 0.04290 | 1.114 | 57.99 |
| 5 | 3.8 | 0.76 | 0.0800 | 0.05795 | 0.9438 | 19.47 |

Data table 4: Data table for wooden pendulum

|  |  |  |  |
| --- | --- | --- | --- |
|  | total length (m) | total mass (kg) | density (kg/m) |
| white | 1.637 | 0.0081 | 0.004948 |
| yellow | 1.721 | 0.0038 | 0.002208 |

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  |  |  |  |  | % difference |
| 1 | 11.2 | 2.000 | 22.4 | 20.87 | 7.072 |
| 2 | 23.3 | 1.000 | 23.3 | 20.87 | 11.00 |
| 3 | 34.7 | 0.6667 | 23.13 | 20.87 | 10.27 |
| 4 | 43.7 | 0.5000 | 21.85 | 20.87 | 4.588 |
| 5 | 52.5 | 0.4000 | 21.00 | 20.87 | 0.6210 |

Data table 5: Data table for standing waves on **white** string- frequency changing

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  |  |  |  |  | % difference |
| 1 | 13.6 | 2.000 | 22.4 | 31.24 | 32.96 |
| 2 | 25.9 | 1.000 | 23.3 | 31.24 | 29.12 |
| 3 | 43.1 | 0.6667 | 23.13 | 31.24 | 29.83 |
| 4 | 56.2 | 0.5000 | 21.85 | 31.24 | 35.37 |
| 5 | 71.5 | 0.4000 | 21.00 | 31.24 | 39.20 |

Data table 6: Data table for standing waves on **yellow** string- frequency changing

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  |  |  |  |  | % difference |
| 70 | 35.0 | 0.8810 | 23.33 | 19.98 | 15.47 |
| 90 | 43.9 | 1.077 | 29.27 | 22.09 | 27.96 |
| 110 | 46.3 | 1.273 | 30.87 | 24.01 | 25.00 |
| 130 | 46.7 | 1.469 | 31.13 | 25.79 | 18.76 |
| 150 | 47.0 | 1.665 | 31.33 | 27.46 | 13.17 |

Data table 7: Data table for third harmonic on **yellow** string- tension changing

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  |  |  |  |  | % difference |
| 70 | 25.1 | 1.763 | 16.73 | 18.88 | 12.08 |
| 90 | 27.7 | 1.959 | 18.47 | 19.90 | 7.454 |
| 110 | 34.4 | 2.155 | 22.93 | 20.87 | 9.406 |
| 130 | 37.6 | 2.351 | 25.07 | 21.80 | 13.95 |
| 150 | 39.2 | 2.547 | 26.13 | 22.69 | 14.09 |

Data table 8: Data table for third harmonic on **white** string- tension changing

**4) Calculations**

Samples from Table 1

% error

Samples from Table 3

Samples from Table 4

Samples from Table 5

Samples from Table 6

Samples from Table 7

**5) Results, Analysis, and Conclusions**

For this experiment, we used several different methods and equipment to experimentally show how equations associated with waves and pendulums play a role in describing oscillation by allowing us to study its many properties–amplitude, velocity, period, wavelength, frequency, and conservation of energy. In the first section of the experiment where we studied spring oscillations, we effectively presented our values for the spring constant k to be within the range of 18.39 N/m and 19.57 N/m, and very close to our theoretical value of 20 N/m. This results in low percent errors, showing that the method we used to find a spring constant was very precise. We have also confirmed that energy was conserved during simple oscillation motion and with low average rates of energy loss/gain of -0.0628% and 0.01128%, theory has been proven.

In the second section of the experiment, we confirmed show a rod and a wooden block closely resemble how simple and physical pendulums work. From comparing the theoretical and experimental values for our periods, we obtained a percent error ranging from 1.156% and 11.88%. A possible source of error in this section of the experiment would be the angle at which we released the pendulum from its resting point before it starts to oscillate. In every trial, we released the pendulum at different angles so this could account for the large percent error from comparing the theoretical period with the experiment period. Another source of error would be the loose screw at the pivot point that does not offer smooth swinging. This would result in the pendulum being wobbly while it oscillates and causes its behavior to deviate from that of an ideal simple pendulum.

In the third section of the lab, we examined the periodic motions by observing a spring acting as a simple oscillator. By putting our data into graphs, we were able to study the relationship between frequency and tension, and frequency and harmonic number. By treating a variable as our independent variable, we can relate our linearization equations toin order to find the density mass of the string. From comparing our experimental density mass with our theoretical density mass, we have obtained percent differences ranging from 16.12% and 67.79%. A possible source of error is the assumption that our derived harmonic number is exact. This can cause a change in frequency and thus, our density mass.

Overall, from this lab experiment, we were able to determine the string density mass simply from studying relationships between tension, frequency, and harmonic number. We also were able to study conservation of energy in oscillations.

**6) Questions**

**Spring Oscillator**

**Q1)** To find the average and standard deviation on the spring constants from Table 1, we used these equations.

σ

**Q2)** To find percent error on the average K value, we used the below formula substituting 20 for the theoretical and the calculated average for the experimental.

% error

**Q3)** Remember that potential energy is and kinetic energy is Our measured values for 350g are

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  |  |  |  |  |  |
| 350g | 0.2580 | 0.2410 | 0.2410 | 0.3500 | 3.60 |

The potential and kinetic energy at the first peak are 0.8894J and 0.01016J respectively.

The potential energy and kinetic energy for the fifth peak are 0.8266J and 0.02144J respectively.

**Q4)**

**Q5)** This system could be modified to behave more like an ideal simple harmonic oscillator by isolating it in an environment with no air resistance.

**Rod Pendulum Part 1**

**Q1)** Yes, for each pendulum we reduced the overall mass between trials from 100g to 0g, this represents a 100% decrease for mass. However, we only reduced the overall length of the pendulum by 10%. Our experimental calculations for the pendulum's period (T), demonstrate the effect that reducing the mass and length have on the period. Since, our T experimental values vary only slightly between the trials, this suggests that the T value depends on length rather than mass.

**Q2)** The shortest pendulum length at .233 meters with the 100g mass had the least percent error at 1.156%

**Q3)** Simple pendulums, by definition, do not change periods with respect to a change in mass. So for our rod pendulum, the trial that yields the smallest change in period between different masses behaves most like a simple pendulum. For our data this was the shorter pendulum. The experimental period (T exp) between 100g and 0g had a difference of .06.

**Rod Pendulum Part 2**

**Q1)** If the brass cylinder is located insidethe rod does not move at all. However, when given a slight push, the rod will oscillate normally. If the brass cylinder is located atthe rod will also oscillate normally. If the brass cylinder is located outsidethe rod continued going in a full circle until it is forced to stop.

**Wooden Pendulum**

**Q1)**

**Q2)** The approximations we made about the physical setup are the length and width of the wooden block. This could affect our calculation for the inertia and thus, affect our measured data. Also, there are holes in the wooden block that is at some distance away from the center of mass. We are also approximating this distance that could also affect the period and moments of inertia.

**Standing Waves**

**(Q1) End of lab report**

**(Q2)**

**Q3)** To find the density mass of a string, we need to use values that stay constant throughout the experiment. In this case, where we treat the harmonic number as our independent variable, the quantities that stay constant are the string’s vibrating lengthand density and the force of tension done by that string. These quantities are represented by the slope of the linear graph, and the y-intercepts of the exponential and power graphs.

**Q4)** In the previous question, we said that the slope of our linear graphs is represented by the length, density, and the tension of the strings. The slope can be described by the equation given below. From (Q2), we found our frequency to be represented by the following equation,

The harmonic number is our independent variable so,

We can then manipulate the equation above to obtain an expression for density mass After doing so, we get

Now, we have obtained an expression for a string’s density in terms of slope, length of the string, and tension. After substituting in our known values, we get the values below as our string’s density.

To find the density mass from exponential and power graphs, we use the y-intercepts as opposed to the slopes. To see why, let’s look at the our equation for frequency again. If we take the logarithm and natural logarithm of the function, we get

Density Masses for White String

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Graph | Linearization Equation | Slope | L (m) | T (N) | Density |
| Frequency vs Harmonic number |  | 9.63 | 1.637 | 2.155 | 0.004057 |
| ln(frequency) vs ln(harmonic number) |  | 0.9755  (y intercept) | 1.637 | 2.155 | 0.004210 |
| log(frequency) vs log(harmonic number) |  | 2.2463 | 1.637 | 2.155 | 0.004211 |

Density Masses for Yellow String

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Graph | Linearization Equation | Slope | L (m) | T (N) | Density |
| Frequency vs Harmonic number |  | 13.78 | 1.721 | 1.665 | 0.00109 |
| ln(frequency) vs ln(harmonic number) |  | 2.3685  (y intercept) | 1.721 | 1.665 | 0.00181 |
| log(frequency) vs log(harmonic number) |  | 1.0286 | 1.721 | 1.665 | 0.00181 |

Notice that our known quantities – n, L, and are the y-intercepts of exponential and power functions. If we use the y-intercept to obtain an expression for density mass, we get

**Q5)** To find the percent difference, we will use the following equation. Our calculated values are the values we computed in the previous question and our measured values are the values we measured during the experiment.

Percent Differences between Density Masses for White String

|  |  |  |  |
| --- | --- | --- | --- |
| Graph | Calculated | Measured | % difference |
| frequency vs harmonic number | 0.004057 | 0.004948 | 19.77 |
| ln(frequency) vs ln(harmonic number) | 0.004210 | 0.004948 | 16.12 |
| log(frequency) vs log(harmonic number) | 0.004211 | 0.004948 | 16.12 |

Percent Differences between Density Masses for Yellow String

|  |  |  |  |
| --- | --- | --- | --- |
| Graph | Calculated | Measured | % difference |
| frequency vs harmonic number | 0.00109 | 0.002208 | 67.79 |
| ln(frequency) vs ln(harmonic number) | 0.00181 | 0.002208 | 19.41 |
| log(frequency) vs log(harmonic number) | 0.00181 | 0.002208 | 19.41 |

**(Q7)** In the previous questions, we have treated the harmonic as the independent variable. Since we are now treating T as the independent variable, the variables the slope represents are different. The quantities that the slope now represents are the harmonic number, the vibrating length of the string, and the density mass of the string.

**Q8)** The slope can be represented by following equation:

After rearranging the equation, we get

To find the density mass from exponential and power graphs, we use the y-intercepts as opposed to the slopes. To see why, let’s look at the our equation for frequency again. If we take the logarithm and natural logarithm of the function, we get

If we use the y-intercept to obtain an expression for density mass, we get

Density Mass of Yellow String

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Graph | Linear Equation | Slope | n | L (m) | Density |
| Frequency vs Harmonic Number |  | 30.947 | 3 | 1.712 | 0.00163 |
| ln(frequency) vs ln(harmonic number) |  | 3.4355 | 3 | 1.712 | 0.00162 |
| log(frequency) vs log(harmonic number) |  | 1.492 | 3 | 1.712 | 0.00162 |

Density Mass of White String

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Graph | Linear Equation | Slope | n | L (m) | Density |
| Frequency vs Harmonic Number |  | 20.658 | 3 | 1.637 | 0.00366 |
| ln(frequency) vs ln(harmonic number) |  | 2.9277 | 3 | 1.637 | 0.00448 |
| log(frequency) vs log(harmonic number) |  | 1.2715 | 3 | 1.637 | 0.00448 |

**(Q9)**

Percent Difference between Density Mass of Yellow String

|  |  |  |  |
| --- | --- | --- | --- |
| Graph |  |  | % difference |
| Frequency vs Harmonic Number | 0.00163 | 0.002208 | 29.70 |
| ln(frequency) vs ln(harmonic number) | 0.00162 | 0.002208 | 29.69 |
| log(frequency) vs log(harmonic number) | 0.00162 | 0.002208 | 29.69 |

Percent Difference between Density Mass of White String

|  |  |  |  |
| --- | --- | --- | --- |
| Graph |  |  | % difference |
| Frequency vs Harmonic Number | 0.00366 | 0.004948 | 29.96 |
| ln(frequency) vs ln(harmonic number) | 0.00448 | 0.004948 | 9.76 |
| log(frequency) vs log(harmonic number) | 0.00448 | 0.004948 | 9.76 |

**Q10)** The data set for third harmonic on white string with tension changing have the smallest percent difference of 29.69%, 29.70%, and 9.76%. Sources of error that could have causes these discrepancies in determining the density mass of the string can be the limitation of measurement devices. Another source of error was the fact when the machine is waving the string, the end of the string holding the mass was swinging up and down. This would have caused the string to lose its perfect oscillation and thus, its harmonic number. This could also account for the large percent errors

we calculated for our density mass of the string.

**Mystery Oscillator**

**Q1)** As the string unwinds when the disk is released, the velocity increases linearly. However, the acceleration stays constant. As for the displacement vs time graph, the shape of the graph represents a sine wave oscillation. At the point where the string has been fully unwounded, it has hit its maximum velocity. And when it starts to wind back up, the velocity decreases linearly, the acceleration stay constant but is of negative value, and the displacement is decreasing with time. In the oscillation from -90 degrees to +90 degrees, the velocity is in the shape of a cosine function as opposed to a linear function in the full winding and unwinding oscillation. The acceleration, in this oscillation, is not constant anymore. Rather, it is in the shape of a sine function. This shows that the acceleration is not constant and that velocity is constantly changing. The displacement vs. time graph’s shape resembles a sine wave oscillation that eventually gets smaller and smaller until it becomes a single, constant line.

**Q2)** The factors contributing to the difference in the two types of motion would be the force of tension exerted by the string. When it is fully wounded, there is less tension on the spring than there is on the string when it is partially wounded. This is particularly why the acceleration is the acceleration in the first oscillation is smaller. In the first oscillation, the radius between the hanger and the center of the spindle is smaller. Thus, the torque on the disk is smaller. In the second oscillation, when the string is partially wounded, the radius is significantly longer, so the torque on the disk is larger and thus, so is the acceleration.