**Experiment 6 and 7: Physical Pendulum Harmonic Oscillations and Waves on Vibrating String**

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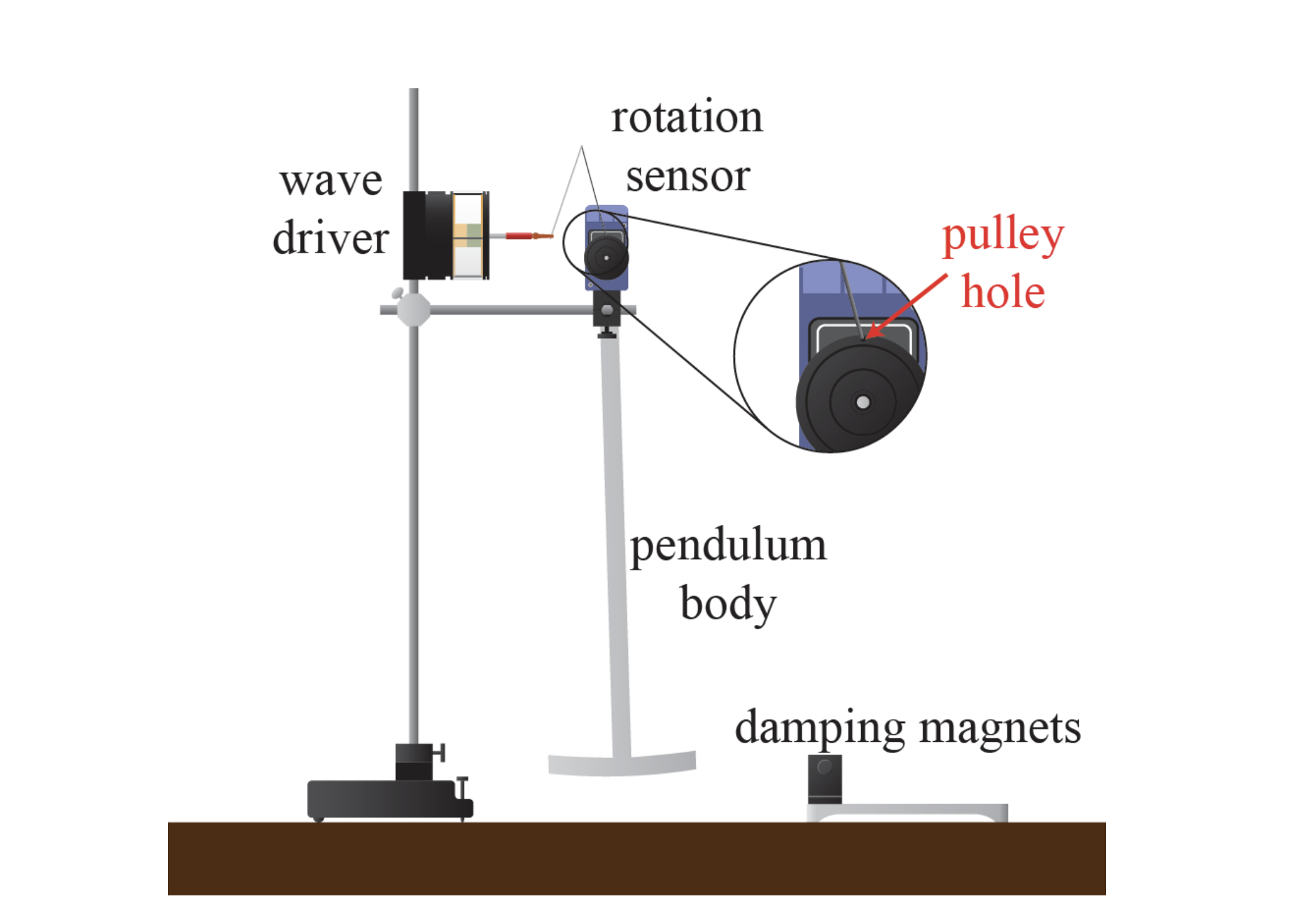
Partner: Shannon Largman

**Abstract**

**Introduction**

**Methods**

*Pendulum*



**Figure X, Physical Pendulum Experiment Apparatus**1**:** This image shows the setup of the equipment that was used for the experiment involving a physical pendulum. For the first part of that experiment, the wave driver was off and disconnected from the rotation sensor. In the second part of the pendulum experiment, the wave driver was used to produce waves in the pendulum. We also included a photogate to record the period of the oscillations at the starting point of the pendulum, but this is not illustrated in the image.

The physical pendulum experiment investigates the damping effect that magnetic field strength has on a swinging pendulum. We investigate the different regimes of damping.

In the first part of this experiment, we look at undriven oscillations. We define the equilibrium point as the point where the pendulum is at rest, pointing vertically downward. We also designated the direction toward the vertical rod as the positive direction and the direction toward the damping magnets as the negative direction. We set our data acquisition system (DAQ) to record the angle from equilibrium in time steps of 0.04 seconds.

For the undamped trial, we move the magnets away from the apparatus to avoid any unintended damping on the system. We placed our photogate next to the vertical rod. We started the edge of the pendulum at the point where it begins to block the photogate sensor. We do this so that we can have a consistent starting point, and also so that we can record the period of the pendulum as it swings. To measure oscillation period, we set up our DAQ so that it records times starting when the photogates goes from blocked to unblocked and finishes timing the oscillation when it goes from unblocked to blocked.

For the damped trial, we place the magnets at the equilibrium point so that the point where the vertical bar meets the horizonal bar in the pendulum sits within the two magnets. To identify the magnet separation at which critical damping occurs, we decrease the separation for every trial, until we reached overdamping. We start at a (50 ± 0.5) mm separation and decrease the distance by about 10 – 12 mm for each trial. We kept the photogate from the undamped trial in the same place so that we have a consistent starting point for each trial. We still record the angle from equilibrium at each time increment with the DAQ.

Next, we look at driven oscillations. For this part of the experiment, we hook up the wave driver to the rotation sensor. We leave the magnet in the same place as they were for the damped undriven oscillation trials (at the equilibrium point). We used a magnet separation of (26.5 ± 0.5) mm for this trial. We used 4 V as our voltage. We turn on the wave driver and determine the resonance frequency by analyzing the Lissajous graphs. We determine the frequency at which the Lissajous plot was horizontal without any tilt.

Also, to determine the amplitude response to frequency of oscillation, we recorded the amplitudes of oscillation for 13 different frequencies. These data points provides us with another method to calculate the Q-factor.

*Waves in a String*



**Figure X, Vibrating String Experiment Setup:** alsdasdf

**Analysis**

*Regimes of Damping*

**Figure X, Regimes of Damping with Different Magnet Separations:** This plot shows the angle of the pendulum from equilibrium during trials damped with magnets. The underdamped data points were produced using a magnet separation of (28.5 ± 0.5) mm. The overdamped oscillation was generated with a magnet separation of (7.5 ± 0.5) mm. The critically damped oscillation used a magnet separation of (13.0 ± 0.5) mm.

Before the experiment, we hypothesized that larger gaps would result in underdamping and smaller gaps would produce overdamped results. We also expect to see that somewhere in between is the gap length where the system is critically damped. Our results confirm our hypothesis. (28.5 ± 0.5) mm was the larger gap and yielded underdamping, and (7.5 ± 0.5) mm was the smaller gap which yielded overdamping. Finally, (13.0 ± 0.5) mm is the separation that we found produces critical damping.

*Resonance*

**Figure X, Undamped Undriven Pendulum Oscillation:** asldkaf

By looking at Figure X above, we see that for each *n* maxima, there are *n* – 1 cycles between each pair of adjacent extremum. To find the angular frequency of oscillation, we need to divide the number of cycles that occur within a certain time range by the magnitude of that time range.

To find the uncertainty, we take the difference between the amplitudes of each adjacent pair of maxima and take the standard deviation. Then we divide by the square root of the number of data points that we used. In our case, *n* is 7 and is 0.002 radians.

With these equations, we find that the angular frequency of oscillation for the pendulum in the undamped, undriven trial is (0.711 ± 0.001) Hz.

*Q-Factor and Line Widths*

The quality factor (Q-factor) in an oscillation describes how damped an oscillator is. Oscillators with low quality factors have resonant frequencies in undriven, undamped cases that are significantly different than the resonant frequency during driven, damped oscillation.1 Higher quality factors mean less difference between these two measured angular frequencies. 1

To calculate the Q-factor for our oscillator, we need to know the angular frequency during the undamped, undriven oscillation trial, and we need to know the damping time. The damping time is the time it takes the amplitude to decrease by a factor of 1/*e*. We already have the angular frequency, so we will calculate the damping time first. To find the damping time, we look at the ratio between two consecutive extremum and also the period of the oscillation.

First, we can find the period of the oscillations.

We find that our average ratio between amplitudes is (0.726 ± 0.016). To calculate the damping time, we use the following equation.

Our value of damping time is seconds. Now we calculate the angular frequency for driven, damped oscillations with the following equation.

Our value of angular frequency for driven, damped oscillations is (0.634 ± 0.020) Hz. Now we can find the Q-factor for this experiment.

Our Q-factor is (1.39 ± 0.04). Q-factor is a dimensionless value and thus has no units. Our Q-factor here is relatively low. Our two values for damped angular frequency are (0.711 ± 0.001) Hz and (0.634 ± 0.020) Hz. These two values fall out of each other’s’ error windows and are statistically significant. We would expect that our values of angular frequency for undamped, undriven oscillations would match those

**Figure X, Damped Undriven Pendulum Oscillation:** This plot shows how the angle of the pendulum (in radians) from equilibrium changed as time went on. The magnet separation in this damped trial was (38±0.5) mm.

**Figure X, Title:** At resonance frequency

**Figure X, Title:** asldkfjlas

**Figure X, Title:** asldkfj

For Figures X and X, it would have been better if we had recorded data at frequencies that were further away from the resonance frequency to exaggerate the differences between the plots.

**Figure X, Title:** This plot shows the amplitude of oscillation at various frequencies. The orange line indicates the height which is times the maximum amplitude of the graph. The resonance width is (0.20 ± 0.05) Hz. From the graph, the two values that intersect with the horizontal line are 0.60 Hz and 0.80 Hz.

We can see from this plot that the peak corresponds to the resonance frequency of (0.711 ± 0.001) Hz, which is what we expect. Our plot does not have the complete Lorentzian shape because some values were measured to be the same for different frequencies. However, if we had increased the precision of the measurement, we would likely have the correct shape.

*Q-Factor via Amplitude Response*

The two frequencies that we measured to have amplitude of are 0.57 Hz and 0.8 Hz. The plot in Figure X nearly captures this, but we did not have the precision that we used when we were trying to find the exact frequencies. These values provide us with a way to calculate the Q-factor with another method.

With this method, our Q-factor is (3.09 ± 0.22). This is higher than the result of our first method which had a value of (1.39 ± 0.04). This was (also) higher/lower than our second result which has value (afsda ± asdf).

**Figure X, title:** This plot shows the Lissajous plots of the two frequencies we found that generated an amplitude response times the response generated by resonance frequency (alex gang)

**Conclusion**

**Bibliography**