PHYS 1P92 Experiment 04

Oscillations and waves

Notes

- Words in blue are links to additional reading or videos.
- Text in gray boxes are hints and things to take note of.
- Text in red boxes are important instructions or prompts that guide you to DISCUSS some of the key RESULTS and CONCEPTS learned in the lab. These prompts may not be the only items that need to be included in your report.

1 Objectives

The goals of this lab are as follows:

- Describe how the sine and cosine functions relate to the concepts of simple harmonic motion
- Describe how the sine and cosine functions relate to the concepts of circular motion

2 Introduction

Periodic motion is a type of motion that repeats itself at regular time intervals. An important example is an oscillation or vibration, which is periodic motion of a particle or mechanical system. Typically this is represented with a sine or cosine function such as the one below.

$$y(t) = A\cos\left(\frac{2\pi \cdot t}{T}\right) = A\cos\left(2\pi f t\right) \tag{1}$$

Recall that frequency and period are inversely proportional ($f = \frac{1}{T}$).

3 Procedure

In this lab, you will need the spring that came with the iOLab device, the string found in the accessory kit, and a bright light source (such as a table lamp or the flashlight from your cell phone). Recording data using the accelerometer, gyroscope and ambient light sensors will give us a set of "wavelike" forms to analyze and help us explore the different parts of oscillatory motion. To ensure the iOLab is recording accurate data, we must first calibrate the sensors we will be using.

Connect the iOLab device and open up the Settings menu. Enable a_y =-g, leaving a_x and a_z as zero. Select the 6-point calibration button and follow all of the steps until you have a green checkmark at the end (this sequence will also calibrate the gyroscope which will be used later on in the lab).

To verify that the calibration worked, take two sets of accelerometer data (2-3 seconds) with the device sitting in $+y$ and $-y$ directions. If the new data in either direction averages to $\pm$g, the calibration was successful. If not, repeat the calibration process. Make sure the table is level and that you do not bump it during calibration.

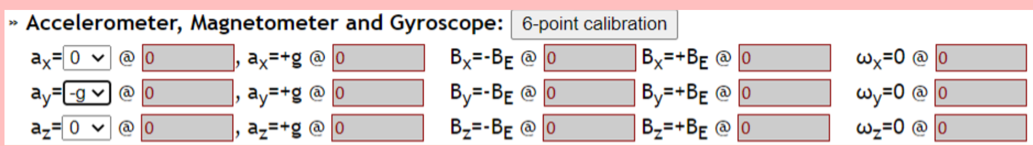

Figure 1: The sensor calibration menu, found under Settings. Since we are looking at motion in the $\pm$y direction for this experiment, enable a_y =-g before you begin calibrating.

3.1 Components of oscillatory motion

We're going to first use the accelerometer to gather "wavelike" data. Connect the spring to the metal hanger attached to the iOLab device on the **opposite** face of the force sensor. Hang the other end of the spring from a fixed point, such as in Figure 2.

Select both the `Accelerometer` and `Wheel` sensors, although we won't use the wheel data at all (it's enabled to reduce the amount of data collected). Carefully apply a gentle push upwards on the iOLab and set it into motion. The motion of the iOLab is in the y-direction, so we need to look at the (`a_y, m/s`^{2}) data.

Record 6 seconds of motion of the iOLab, but make sure you start recording data **after** the iOLab has gone through a few *cycles/periods* of motion. Save the accelerometer data to your computer.

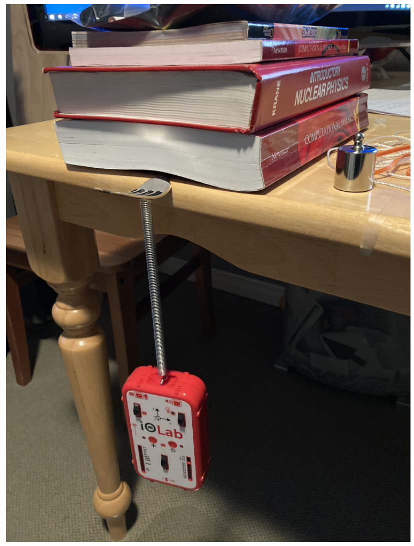

Figure 2: The setup for iOLab hanging from a spring. In this example, a fork was used as the hanging point, held by a large pile of books. Note the orientation of the iOlab and where the spring is connected.

> Try not to let the iOLab twist or swing in any direction. You want it to just be gently bouncing up and down in the y-direction.

3.1.1 Waves : period and frequency

Let's determine the **period** of the motion. The period is the time between two identical points on the wave, such as the peaks. What is a good strategy to measure it? We could just measure the time between two peaks, because they are easy to identify.

> Zoom into the top of the first peak of the motion, and record the time point of the first peak of the motion. Call this point t_1
>
> NOTE: do not use the scroll wheel, if you just click and drag on the graph you can zoom in to look at points without using box select as the zoom tool is the default.
>
> - What is the step size of the data in time? Call that Δt.
> - How many data points make up the top of the peak? Call that n.
> - Given the parameters Δt and n, can you come up with your own algebra formula for determining the uncertainty of the time point of the peak? Explain in your

discussion how you determined this formula with the physical rational for your choice. Let the uncertainty be called σ_1.

> For this formula we are more concerned with your rational and physical reasoning than the exact formula you determine.

- Based on your recorded values, state t_1 with its uncertainty.
- What would be the uncertainty if you tried this method on different peak of the wave? Why is that?

Assume we had the time value for the *next peak*, $t_2 \pm \sigma_2$.

Using error propagation, work out the uncertainty of the period, σ_T, in calculating the period from

$$T = t_2 - t_1 \tag{2}$$

taking into account what you know about σ_1 and σ_2.

NOTE: when writing your uncertainties take the time to write it in algebraic form first before you substitute in your values this helps TA's determine where you may have gone wrong!

Now assume we had the time value for the peak *5 cycles away from the first*, $t_6 \pm \sigma_6$.

Using algebra and error propagation, perform the following:

1. Using t_6 and t_1, solve for an equation for the average period for a single oscillation. Call this average period T_{avg}.
2. Find the uncertainty of T_{avg} of one cycle from σ_6 and σ_1.

Has the uncertainty improved or worsened by this method?

Using a value you previously calculated for period, find frequency. Why did you choose this value for period?

Explain how these variables influence the shape of your oscillating curve.

3.1.2 Waves : amplitude

Now we're going to determine the **amplitude** of the motion. This is the maximum displacement of an oscillating object from it's equilibrium point.

THEORETICAL PREDICTIONS

Based on equation 1 what SHOULD the average value of y be between the time points $t = 0$ and $t = T$?

What are the maximum and minimum values of y in equation 1 between the time points $t = 0$ and $t = T$ that you observe? At what time points does it reach those values? Call these $y_{\max}$ and $y_{\min}$, $t_{\max}$ and $t_{\min}$.

Based on the the data you collected what should the UNITS of the amplitude be?

Pick out one cycle of your wave data. Use the "selection" tool on the graph to highlight in yellow only those points that are part of one cycle, as best as you can.

What is the average of the data over that cycle (Y_{avg})? The graph statistics will give you $\bar{y}$ and the uncertainty $\sigma_{\bar{y}}$.

What is the greatest $y_{\max}$ of that cycle? What is it's uncertainty? What is the least $y_{\min}$ of that cycle? Explain your methods how you chose those points, and how you utilised iOLab Online to find those values.

What is the amplitude A of your wave data?

Plan out how you might use the parameters Y_{avg}, $y_{\max}$, or $y_{\min}$, to write an algebraic expression for A. Then determine the numerical result, and its uncertainty.

How might you modify equation 1 to incorporate the value of Y_{avg} from your trial?

> **Hint:** How would you account for a shift in the y-axis on your curve

3.1.3 Waves : Phase

Waves don't always begin at sin(0) or cos(0). Thus waves are said to be **phase**-shifted.

THEORETICAL PREDICTIONS

Based on equation 1 what is the value of y at $t = 0$?

Looking at your collected data, what is the value at $t = 0$?

Let's modify your new wave equation from the previous section to include a phase ϕ, by adding it to the cosine function like this:

$$\cos\left(\frac{2\pi \cdot t}{T} + \phi\right) \tag{3}$$

You now know all the parameters except ϕ. However, it is possible to find the value of ϕ from the other parameters and one data point, precisely the value of y at $t = 0$.

Write down the full equation of the wave $y(t)$ in terms of the amplitude A, the period T, the phase ϕ, and the average Y_{avg}.

Substitute your predicted values for amplitude A, period T, and the average Y_{avg}. Use initial time **t=0** in your equation (created above). Solve this equation for ϕ. **DO NOT calculate the uncertainty of ϕ.**

3.1.4 Waves : The Wave Equation

Now let's fit the wave data to a wave equation, using your measured values of period, amplitude, and phase as initial guesses.

Select the entire data set in the graphing window.

In the Fit section, choose the function `y=A*sin(B*x+C)+D` from the drop-down menu of functions, and then replace `sin` with `cos`.

What do the fitting parameters `A`, `B`, `C`, and `D`, each represent in terms of T, A, ϕ, and $\bar{y}$? Write out your equation and compare it to the fitting equation to determine the numerical values of your guesses of `A`, `B`, `C`, and `D`.

Enter the initial guesses of `A`, `B`, `C`, and `D`, and click the `Fit` button.

Record the fit values of `A`, `B`, `C`, and `D`.

> If you cannot get the function to fit your data, look back at your modified version of equation 1 to make sure you have not forgotten any constants that may be 'lumped into' one of the values of A, B, C, or D.

Record the values of T, A, ϕ, and Y_{avg} computed based on the fit values of `A`, `B`, `C`, and `D`.

Save a graph of the fit for your report.

3.2 Uniform circular motion and waves

The cosine function of equation 1 shows that simple harmonic motion and waves are also related to circular motion. But a cosine or sine function is just the simplest mathematical form of periodic motion, making the concepts a little easier to learn.

The data we take in experiments does not need to look like a cosine function at all to be periodic. It just needs to have some repeating signal.

Remove the spring from the iOLab, and hang your iOLab from a piece of string in the same way it was hanging before.

Nearby, you need a source of bright light, nearly level with the light sensor. This can be a window on a bright day, a desk lamp, or the flashlight from your cell phone. An overhead room light will not work; we want the light shining right at the light sensor.

Select the `Gyroscope` and `Ambient Light` sensor. Gently wind up the iOLab and let it spin freely. Collect about 10 seconds of data.

Save both data sets to your computer.

In the `Ambient Light` sensor data, you should see a spike each time the light sensor is facing the light. Save an `Ambient Light`-time graph for your report.

The iOLab is rotating around the y-axis, and the `gyroscope` sensor will measure the angular velocity in degrees per second. Save an ω_y-time graph for your report.

You should see from the light sensor data a spike in light intensity each time the sensor was facing the bright light source. The data won't look like a cosine function at all, but it can be modelled using the methods we've discussed previously, to a an extent.

> Using a similar method to that of 3.1.1 predict the value of the
>
> 1. period, and frequency
> 2. their respective errors.
>
> **Select a data region that exhibits periodic motion.** Explain your work. Why did you choose this region? Did you omit any data? How did you calculate the uncertainty for the above?
>
> What was the time range you chose to use? How many revolutions did the iOLab make in that time range?
>
> Based on the number of revolutions the iOLab made, and the time range you chose, what was the average angular velocity of the iOLab, measured in degrees/second?
>
> > **Tip:** Remember there are 360 degrees per revolution.

You should see from the gyroscope data that the iOLab slowly increased its angular velocity as it speeds-up, then decreased as it unwinds the string.

> Over the same time range you used above, select in yellow the ω_y data and use the graph statistics to determine the angular velocity and uncertainty. Do your two values of angular velocity agree?
>
> > **Note:** dps stand for degrees per second.
>
> Does the fact that it may be speeding up or slowing down change your thinking on how you calculated the period of the revolutions earlier?

Finishing Up

Now that you have completed the lab, be sure you filled out all portions of the data tables (templates found in the Resources Tool on Sakai), include figures, and develop a robust discussion using prompts found throughout the manual.
Ensure to give yourself enough time to complete the report and to hand it in by the due date

as late lab reports will not be accepted! If you have any questions please attend a live lab session to get help from one of the course lab demonstrators, or email Phys1P92@brocku.ca.