§ 1 Introduction

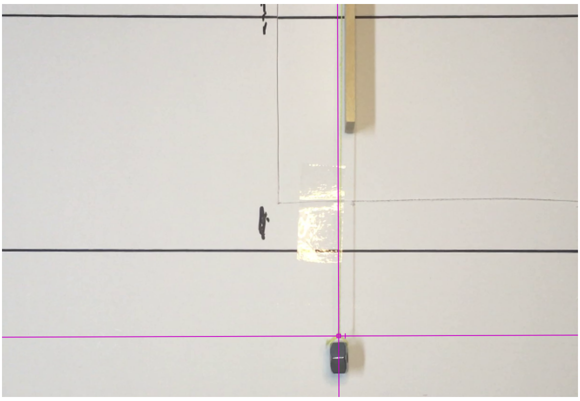
In this laboratory you will do some preparatory observations that will help you when you take up the ideas of kinetic and potential energy later in the semester. We will make observations of the position and speed of a pendulum and then discover a surprising relationship between the position and speed. As always careful set up of the measurements will make this surprising relationship more apparent.

§ 2 Make a video

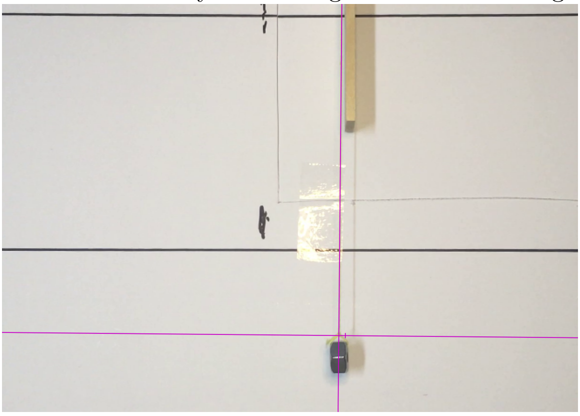
Procedure 2.a
Set up a pendulum as directed by your instructor.
• Have a reference rectangle behind the pendulum visible in the video.
• The beginning of the video should have the pendulum at rest hanging straight down.
• Measure the distance L from the camera to the reference rectangle, and the distance D from the pendulum to the reference rectangle. Write down the values of L and D.

Record a video of a pendulum swinging.
• The swing of the pendulum should not be very large.

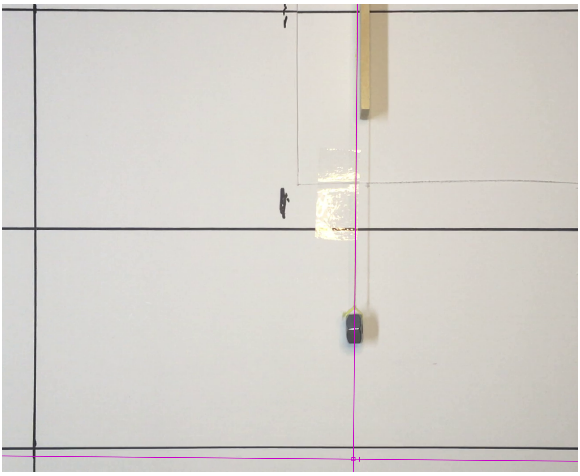
Procedure 2.b
Import your video into Tracker
• Use the perspective filter to correct the perspective.
• Set the scale, using the known length of your reference rectangle.
• Set the axes. You should do this in four steps. First go to a frame in the video where the pendulum is at rest hanging straight down. Second set the origin of the axes so that it is at the point where the string attaches to the mass.



Third rotate the axes, until the y-axis is aligned with the string. Note that if you "grab" the x-axis you can rotate the axes. So grab the x-axis and nudge it a little bit until the y-axis is aligned with the string.



Fourth move the origin down below the mass.



Set the axes so that the origin is someplace below the lowest point in the motion of the pendulum. The vertical axis needs to be parallel to the string of the pendulum when it is hanging straight down. Track the motion for two full oscillations, left right left right. Save the data table to a txt file.

Procedure 2.c

Get the application for this lab [MSwin, macOS] from the class website. Run `Lab3p1`, feeding it the Tracker data for the motion, and setting the values of L and D. The program will produce some graphs. The questions below will guide you through these graphs one at a time.

▷ Question 1

Look at figure 2. This figure shows the vertical position y and the speed $v = |\vec{v}|$ of the object on the end of the string. Notice in the graph that when the y increases that v decreases. This relationship between the v and y should be familiar. Think about your experience of riding a bicycle both up hill and down hill without pedaling. Based on your past experience state what this graph is showing.

▷ Question 2

This qualitative relationship between the y and v is something that we are familiar with, what is striking is that there is a strong mathematical relationship between them also. Look at figure 3 which is a graph of y and v^2. Our measurement of speed is noisy, but it is plausible that one graph is the other graph flipped upside down. To test this hypothesis look at figure 4 which is of y and $-v^2$. Looking through the noise do they seem to move up and down together?

▷ Question 3

In figure 4 the program puts the graphs of y and $-v^2$ on top of each other in order to see if the shapes were similar. But they were not actually graphed on the same axes. They cannot be graphed on the same axes because they do not have the same units. If we multiply y by $g = 9.8\frac{\text{m}}{\text{s}^2}$ then gy will have the same units as v^2. What are these units? In figure 5 is graphed gy and $-v^2$. You will notice that they are no longer on top of each other as they were in figure 4, they are offset and different amplitudes. Why is this? You will now correct for this offset and amplitude difference. Look at figure 6, this is a graph of gy and $b - cv^2$ for $b = 0$ and $c = 1$ which is exactly the same as figure 5. The difference is that you can adjust the values of the constants b and c, which move and stretch $-v^2$. Adjust the constants b and c until the graph of gy and $b-cv^2$ are as similar as possible. What are the values of your constants? Looking through the noise of the measurement would you say that $gy = b - cv^2$? A PDF of graph 6 is saved automatically.

▷ Question 4

Now look at figure 7, which graphs gy and cv^2 and $gy+cv^2$. Based on what you learned from figure 6 what do you expect $gy + cv^2$ to be? Is this what happens in figure 7? A PDF of graph 7 is saved automatically.

▷ Question 5

What you have seen in this lab is not specific to the pendulum, it is indeed broadly applicable: for many systems there is a function of the position $U(x, y)$ such that $U(x, y) + cv^2$ is constant. You will learn about this function $U(x, y)$ in class. For now let us trust that the equation you got in this lab $gy + cv^2 = b$ will work for any kind of rolling freely up and down hills with the constant c that you found for the pendulum applicable to all situations, while the constant b will vary. Image that you are at the bottom of a hill ($y = 0$) on a skateboard rolling at a speed of $10\frac{\mathrm{m}}{\mathrm{s}}$ toward the hill. You roll up the hill, the hills slows you down until you stop.

- What will be your speed when vertical positions is $y = 2.0\mathrm{m}$?
- What will be your vertical position y when you stop?

Hints: Use the same constant c that you did for the pendulum, but the constant b will be different. You can find the value of b from your known speed at the bottom of the hill.