Name: ______________________

Partner(s): ______________________

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Date: ______________________

The Nature of Hypothesis
The Simple Pendulum: A prototypical Physics Lab

1. Purpose:

The purpose of this experiment is to introduce you to the scientific method by investigating the behavior of a very familiar and apparently simple apparatus, the simple pendulum.

2. Introduction:

A characteristic property of any pendulum is its period, ***P***; the time it takes the pendulum to execute one complete swing. What determines or affects the period of the pendulum? A few guesses include:

- Could an executive order from the White House affect the period?
- An order from the Pope?
- Psychic forces?
- Race or gender of the person taking the data?
- Whether the experiment is done by aborigine tribes in Australia or by Tibetan monks in the Himalayas?
- The mass of the pendulum?
- The thickness of the string? ...

* Add any of your own ideas, which you might explore today:

There are many ways to try to find answers to a question like this.

- You could ask your parents: don't they know what is right?!?
- You could ask the priest: he could look it up in the Bible?!
- You could ask one of the physics faculty: they *must* know the answer?!
- You could look it up in a text, which must tell the whole truth and nothing but!
- Congress could pass a law regarding how pendulums should behave!
- You could take a vote: the answer that gets the most votes will be the true one!
- You could use pure logic (without reference to measurements) to find the only logically consistent answer!

The way we physicists, and scientist, in general, approach a question like this is to say: "Why keep arguing about it? Why not go ahead and try to measure it and find out for ourselves?"

While this may sound obvious to most of you, the notion that ***you*** can discover some truth by experimentation and analysis is not very ancient. More importantly, while it happens to be one of the central beliefs of scientists in general and physicists in particular, it is not universally agreed upon.

3. Procedure:

We give you, as a gift, an initial hypothesis - the period ***P*** of the pendulum might depend upon three of the most readily apparent physical parameters:

- the length of the pendulum, L
- the amplitude (how large the swing is), θ_o
- the mass of the bob, M

You might ask whether it's also reasonable to expect that, say, the gravitational strength, ***g,*** will affect the period, ***P***. However, you should keep in mind that if it *isn't* "testable," then it isn't a *scientific* hypothesis. Unfortunately, we cannot turn off earth's gravity or vary it. (Or can we?) Maybe you'll come up with an even better hypothesis!

We guide you towards testing this hypothesis by asking you to find the *functional form* of the period's dependence upon these parameters. However, your work is ***not*** done once a graph is "fit" to some equation. The ultimate goal with any experiment is to extract physical *meaning* from any charts and graphs you create - or at least to decide whether meaningful statements may be made on their basis.

Let us know how much confidence you think we should have in your results.

Dream a little

When Galileo was 19 years old, he would often find himself daydreaming in church. Sometimes, his trance was induced by staring at the gentle swaying of the cathedral lamps, which were each suspended by a very long cord from the ceiling. According to legend, Galileo's wistful observations during mass led to the development of the pendulum clock, the first *reliable* clock.

Unlike Galileo, who had to use his own pulse as a crude timer for his early observations, you have the luxury of using a high-precision computerized timer, an "electric eye" of sorts. The instructor will explain the use of the infrared beam timer and the associated software. If you are sufficiently confused by your instructor's explanation, simply play around with the software and examine the various modes of the timing program.

Make it a *habit* (in this and every lab) to repeat each measurement a few times (and let us know when you do). Note the variations between trials.

Since the computer keeps track of the time for each swing, you can take the average of ten trials to improve your accuracy. Alternately, for a given choice of L, M and θ_o, you can find the period $\boldsymbol{P}$ by measuring the time it takes for, say, 10 oscillations and divide this time by 10. Describe which method you chose and why below.

While you are free to explore further, suggested ranges are:

L: from 10 or 20 cm, up to 100 cm
M: 50 gm - 250 gm
θ_o: 10° - 30°

Again, be sure to specify the details of your measurement:

4. *Data:*

4.1 Part 1: Period as a function of Mass, P(M)

L = ________cm

θ_o = ________° **(Always *EXTEND* any data table as needed!)**

Trial	Mass ( )	Period ( )
1		
2		
3		
4		
5		

Once you have your results in tabular form, comment upon them in English. Brief *verbal* comments generally add enormously to your work. Make this a habit: lab notebooks should be a record of *thought* and analysis, not just a log of dial settings and readouts.

4.2 Part 2: Period as a function of Amplitude, P(θ_o)

L = __________ cm
M = __________ gm

Trial	Amplitude ( )	Period ( )
1		
2		
3		
4		
5		

State these results in English and comment upon them. (Do I really have to keep reminding you to do this? Please keep this rule in mind for *all* of your lab work.)

4.3 Part 3: Period as a function of Length, P(L)

M = __________ gm
θ_o = ________°

Trial	Length ( )	Period ( )
1		
2		
3		
4		
5		

❖ State these results in English and comment upon them (Last time I'll say it)

❖ Additional comments on the data or the procedure:

5. *Analysis:*

What you have done so far is conveniently described by a favorite phrase of mine: you have gotten “a handle on this pendulum thing.” You have probed the pendulum’s behavior by discovering and then varying a few parameters. You have a sense of what the most important/relevant variables are and how they affect the dynamics of the pendulum. Once you have a "handle" on a problem, you are ready to make further progress.

Where do you go from here? Well, it depends upon the stage of history you are at. If you lived in the early sixteenth century, you would have to start building your own "theory", which, by the way, is a fancy name for "a model of reality". Today however, you can jump ahead. You are riding the giant shoulders of many scientists, not the least among whom is the legendary priest and tax collector from Cambridge, England. Yes, you guessed it: Sir Isaac Newton. Your experiment is yet another test of whether or not Newton's laws are valid!

Newton's laws of mechanics, when applied to a simple pendulum (we will study this in the next few weeks), offer a more explicit hypothesis - predicting the relationship given by Equation 1.

$$P = 2\pi\sqrt{\frac{L}{g}} \tag{1}$$

where ***g*** is the acceleration due to gravity, whose value (according to your text) is **9.80 m/s^2**. In the context of the experiment you have done, Newton's theory makes four relevant redictions that you can examine your data.

5.1 Part 1: Period as a function of Mass, P(M)

According to Equation 1, the period should not depend upon the mass at all! What did you find? Attach any relevant analysis and plots below. Comment on your analysis.

5.2 *Part 2: Period as a function of Amplitude, P(θ_o)*

According to Equation 1, the period should not depend upon the initial angle at all! What did you find? Attach any relevant analysis and plots below. Comment on your analysis.

5.3 *Part 3: Period as a function of Length, P(L)*

According to Equation 1, the period *should* depend upon the length. First a comment on language: You recall from high school that $\sqrt{L} = L^{1/2}$. We say that 1/2 is the "exponent". Clearly we are not talking about an "exponential function" (*i.e.*, one that involves the natural ***e***). We also say that L is raised to the 1/2 "power". Thus, the form:

$$y(x) = a\,x^{b} \tag{2}$$

is called a "power law", with exponent ***b***.

In this case, your analysis is guided by the prediction of Newton's laws, which suggest that you try the same form as in Equation 2. If we let y = P and x = L, Equation 2 takes the form:

$$P(L) = aL^{b} \tag{3}$$

where ***a*** and ***b*** are simply two "fitting parameters" that one adjusts to achieve the best possible match between your data and this "hypothesized" functional form. Clearly, your hypothesis (Equation 1) leads you to expect that the data should be best fit when the parameters ***a*** and ***b*** have numerical values given by

$$a = \frac{2\pi}{\sqrt{g}} \tag{4}$$

$$b = \frac{1}{2} \tag{5}$$

In the early days of physics, this took time and ingenuity to establish. We spoil you by letting the computer do some of this analysis. Enter your data $P_{exp}(L)$ into your favorite graphing routine. Ask the software to fit the data to a power law form, and it will *automatically* examine many values for ***a*** and ***b***, testing each set of possible values using a “least squares algorithm” until it optimizes the “fit” of the power law to your data. It will then report the “best fit” values of ***a*** and ***b***, as well as supply values of $P_{th}(L)$, the predicted function using the best-fit values for ***a*** and ***b***.

- Copy the fitted values of the parameters into the table below:

	b	a ( )
Experimental		
Theoretical		
% error		

- Next, you should visually examine the “quality” of the fit. Examine your data $P_{ex}(L)$ and the fitted curve, both plotted on a single graph. Clearly, ***P*(*L*)** is a *non*linear function. [You could also try to "fit" a linear function and convince yourself of this. You will see how bad the fit turns out to be.]

- Print out a clearly labeled (and appropriately sized) graph of your data and the computer–generated fit and attach it to your notebook.

- Comment upon the level of agreement between theory and experiment. Does your data agree with what is predicted by Newton’s Laws? Why or Why not?

6. *Questions:*

i. How did you decide which two physical points to use in measuring the length of the pendulum?

> **Hint:** Is the center of mass concept useful here? (By the way, didn't we mention that it's valuable to read every lab carefully *before* beginning work? You would be at a great advantage if you considered this concept *before* making your measurements!)

ii. Is 9.80 m/s^2 an appropriate value for $\boldsymbol{g}$ on the Illinois Wesleyan campus? The CRC (Chemical Rubber Company) Handbook in the lab will be worth consulting, if you know our latitude.

iii. Using the theoretical formula, predict the period of a pendulum of some specific length, then make a pendulum that length and *test* your prediction.

7. Initiative:

8. Conclusions: