Physics 11: Introductory Activity - The Simple Pendulum

Research Questions:

- ***What factor(s) determine the period (T) of a Simple Pendulum?***
- ***What effect (if any) do each of the factors have on the period?***

Learning/instructional objectives of this activity include, but are not limited to …:

- **Experimental physics skills**
  - Experimental design
    - Planning controlled experiments; designing experimental methods; choosing appropriate equipment; optimizing experimental set-up; working effectively as a member of a team
  - Measurement
    - Use of measurement tools; careful attention to hand-eye co-ordination
    - Identifying sources of error and measurement limits
  - Graphing
    - Drawing graphs using methods standard to the discipline (physics methods)
    - Interpreting graphs by making sense of the shapes of the graphs, and what those shapes imply about data trends and mathematical patterns (pattern seeking)
    - Develop and interpret the equation of a straight line graph (equation in the form $y = mx + b$)
  - Data analysis
    - Interpreting data and drawing conclusions, including specifying and articulating the limits to the conclusions (research results tell us some things, but not everything – there will always be many questions left unanswered, and new questions will arise)
  - ***Instructional Resources:*** *Resources will be provided in the form of handouts, also available posted on the class website.*

- **Scientific literacy**
  - Write and explain your ideas and findings, in paragraph form; Appropriate use of visual representations such as diagrams, data tables, and graphs.
  - ***Instructional Resources:*** *Provided in the form of handouts (also available posted on the class website)*

- **Physics theory**
  - *Simple Harmonic Motion*, applied to the Simple Pendulum
  - ***Instructional Resources:***
    - *Notes/lessons in class (definition of period and frequency; characteristics of the "simple pendulum"; period of the simple pendulum)*
    - *A VERY USEFUL online simulation to deepen your understanding:* *https://phet.colorado.edu/en/simulation/legacy/pendulum-lab*

Part 1: Consider the Problem (small group discussion and idea sharing):

With your group, consider the following ideas and questions. Write and/or draw your ideas about each of the questions (rough/point form is ok).

1. Consider the term, "***Simple Pendulum***"
    a. What does the term "***pendulum***" mean? Use words and diagram(s) to define the characteristics of "pendulum". Your level of clarity and precision should be such that readers are be able to imagine both what a pendulum ***is***, and what it ***is not***.

    b. The type of pendulum we will be investigating is ***simple***, but other types of pendula (pendulums) exist outside the lab. In terms of physical design, ***differentiate*** between "*simple*" and "*non-simple*" pendula (what are the defining characteristics of each?).

2. ***Period "T" (s)*** = the time for one complete cycle of a repetitive (periodic) event
    a. A pendulum swinging freely is an example of an object in periodic motion. Consider the world around you – both the natural world, and human created objects and concepts. List as many other periodic events as you can think of:
        i. Natural

        ii. Human created objects and concepts

b. Imagine that you are observing a pendulum swinging through repetitive cycles, unobstructed (an "ideal" pendulum with no friction and no damping). How can you identify the start and end of a single cycle? (draw diagrams to show/explain your ideas).

c. In your lab, you will be using a handheld stopwatch to measure the period (T) of a pendulum.
   i. List as many sources of error that you can think of, inherent to using a handheld stopwatch to measure the time for the swing of a pendulum.

   ii. Suggest a strategy or strategies for minimizing the effects of the inherent sources of error associated with using a handheld stopwatch:

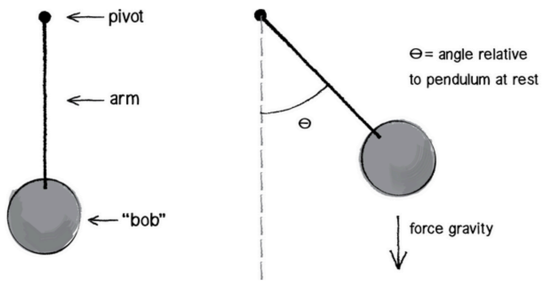
   iii. Measurement limits: considering both the measurement limit of the stopwatch (measures to the nearest _________ s), and sources of error associated with measurement technique, estimate the approximate limit to precision of your measurement of period: ± _______________ s

3. **Mass "M" (kg)** = mass of the simple pendulum (in kg). You will determine the mass of the simple pendulum by using an electronic balance.
   a. List as many sources of error as you can, inherent to using an electronic balance for this purpose.

   b. Suggest a strategy or strategies for minimizing the effects of the inherent sources of error associated with using an electronic balance for this purpose:

   c. Measurement limit: The electronic balance measures to the nearest _________ kg. Therefore, the limit to which the mass of the pendulum can be determined is approximately ± _______ kg.

4. **Displacement Angle "θ"** (°) = The angle relative to the rest position (vertical) that the pendulum string makes the instant before it is released (shown as θ in the diagram below).



Suggest and describe 2 different strategies for determining the displacement angle (yes, there are 2 reasonable methods that require equipment commonly found in physics and math classrooms).

5. **Length "L" (m)** = the distance from the pivot point of the pendulum to the centre of mass of the bob.
   a. What does the term "*centre of mass*" mean?

   b. List sources of error associated with measuring the length of the pendulum.

   c. Estimate the limit to which the length can be measured: ± _________m.

6. Next class you will collect data and start the data analysis. You will take measurements for 10 different data points, and complete 3 trials for each data point.
   a. Why do scientists typically complete multiple trials for each data point? What is the advantage of multiple trials (rather than just one)?

   b. After you graph the data, what evidence will you look for to determine whether or not 10 data points is sufficient? (perhaps more than 10 are needed? Or, perhaps fewer than 10 would be sufficient?)

Part 2: Data Collection and Analysis

Pre-lab Lesson/handouts:

- Graphing Guidelines (*handout + lesson*)
- Determining Relationships from Graphs (*handout + lesson re: straight line graphs and y = mx + b)*
  - *Complete and hand in this worksheet for the teacher to check*

Activity:

Apparatus:

- various masses, from 50g to 500g
- string
- ring stand
- meter stick
- stop watch
- electronic balance
- scissors
- mm rule graph paper
- *for demonstration only: Photogate timer*

1. **Collect data** and complete the data tables*:*
   - Period "T" (s) vs Mass "M" (kg), while keep length and displacement angle the same in every trial (L and θ are controlled)

Period "T" (s) vs Mass "M" (kg) of a Simple Pendulum

(Constant length, Displacement Angle less than 15 degrees)

1	2	3	4	5	6
	Trial 1	Trial 2	Trial 3	(Average of the 3 trials)	
Mass "M" (kg)	Time for 10 cycles "t"(s)	Time for 10 cycles "t"(s)	Time for 10 cycles "t"(s)	Time for 10 cycles "t"$_{ave}$(s)	Period "T"(s) = time for one cycle = $t_{ave}/10$ *[column 5 divided by 10]*
0.050					
0.100					
0.150					
0.200					
0.250					
0.300					
0.400					
0.500					
0.550					
0.600					

- Period "T" (s) vs Length "L" (m), while keep mass and displacement angle the same in every trial (M and θ are controlled; θ should be kept small, at 15° or less)

Period "T" (s) vs Length "L" (m) of a Simple Pendulum

with a mass of 0.200 kg, and Displacement Angle less than 15 degrees

1	2	3	4	5	6	7	8
(ideal – try to get the string close to this length)	(measured ***actual*** value)	Trial 1	Trial 2	Trial 3	(Average of the 3 measured trials)	(calculated from measured value)	(calculated from measured value)
Length "L" of pendulum (m) [ideal]	Length "L" of pendulum (m) (to the centre of mass of the pendulum)	Time for 10 cycles "t"(s)	Time for 10 cycles "t"(s)	Time for 10 cycles "t"(s)	Time for 10 cycles "t_{ave}"(s)	Period "T"(s) = time for one cycle = $t_{ave}/10$ *[column 6 divided by 10]*	Period squared "T^2"(s^2) *[column 7, squared]*
1.00							
0.90							
0.80							
0.70							
0.60							
0.50							
0.40							
0.30							
0.20							
0.10							

2. **Draw graphs** for each of the data tables (place ***Period "T" on the y axis*** in each case)
   - Period "T" (s) vs Mass "m" (kg)
   - Period "T" (s) vs Length "L" (m)

***** **Submit these graphs to your teacher** next class. If there are errors you will have the opportunity to make corrections *****

Analysis Questions:

1. For each of the graphs, describe the mathematical shape in words (straight line, or curve).
   a. Period "T" (s) vs Mass "m" (kg)

   b. Period "T" (s) vs Length "L" (m)

2. If any of the graphs appear to be "straight line", generate the equation of the line in the form ***y = mx + b***

3. Based on the shapes of the graphs, to the best of your ability, complete the following statements:
   a. Period "T" (s) vs Mass "m" (kg)
      i. *"It appears that the period of a Simple Pendulum _________ (does/does not) depend on mass".*

      ii. Explain your reasoning:

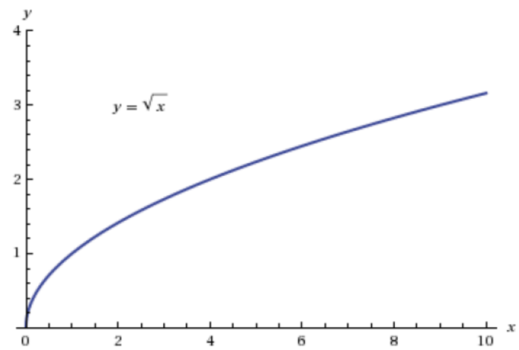
   b. Period "T" (s) vs Length "L" (m)
      i. "It appears that the period of a Simple Pendulum _________ (does/does not) depend on the length of the pendulum".

      ii. Explain your reasoning:

Part 3: Refining the Analysis

Period "T" (s) vs Length "L" (m): The period of a Simple Pendulum ***DOES*** depend on length, but not linearly. The graph of *T vs L* is a smooth curve, not a straight line. Mathematical analysis and pattern finding is much easier with straight line graphs, so physicists typically prefer working with straight line graphs. One method for trying to create a straight line graph from non-linear relationships (straightening the curve), is to try squaring one of the variables. If the mathematical relationship between the variables is quadratic, the new graph, with one variable squared, will form a straight line.

According to accepted theory of Simple Pendulums, if enough data points are shown, the graph of *T vs L* looks much the graph below. So, squaring the variable on the y axis (T, in your case), and graphing ***T^2 vs L***, should result in a straight line graph.



To attempt to straighten your graph you will graph ***T^2 vs L***, in addition to ***T vs L***.

1) State which of the variable (period vs length) is **dependent**, and which is **independent**: (refer to the guidelines at the end of the assignment re: identifying variables)
    a. Dependent: ____
    b. Independent: ______________________________________

2) Calculate the slope of the ***Period Squared "T^2" vs length "L" of a Pendulum*** graph. (show all work)

    ____

3) State the equation of the line of the ***Period Squared "T^2" vs length "L" of a Pendulum*** graph (in the form *y = mx + b*).

    ____

4) The theoretical equation for the period of a pendulum is: $\mathbf{T^2 = [4\pi^2/g]L}$. Compare the pendulum equation with the general format of the equation of straight line graphs, *y = mx + b*

    a. Which of the variables in the theoretical equation represents the "y" value? ________________

    b. Which of the variables represents the "m" value (slope)? ____________________

    c. What is the theoretical value of "b", the y intercept? ____________________

5) % error calculation:
   a. Use your answer in 4(b) to calculate the accepted value for the slope of the T^2 vs L graph (note: g = 9.80m/s^2):

   ____

   b. State your experimentally determined slope of the T^2 vs L graph (restate your answer to question 2)

   ____

   c. Determine the percent error of your experimentally generated slope, comparing your results with the theoretically expected value for the slope of the graph. (show your work)

   % error = [(experimental value – accepted value)/accepted value]×100% = ?

Identifying Independent **and** ***Dependent*** **Variables**

(summarized from: http://nces.ed.gov/nceskids/help/user_guide/graph/variables.asp)

An **independent variable** is a variable that isn't changed by the other variables you are trying to measure. For example, someone's age might be an independent variable. Other factors (such as what they eat, how much they go to school, how much television they watch) aren't going to change a person's age. In fact, when you are looking for some kind of relationship between variables you are trying to see if the independent variable causes some kind of change in the other variables, or dependent variables.

A **dependent variable** is something that depends on other factors. For example, a test score could be a dependent variable because it could change depending on several factors such as how much you studied, how much sleep you got the night before you took the test, or even how hungry you were when you took it. Usually when you are looking for a relationship between two things you are trying to find out what makes the dependent variable change the way it does.

Many people have trouble remembering which the independent variable is and which the dependent variable is. An easy way to remember is to insert the names of the two variables you are using in this sentence in the way that makes the most sense. Then you can figure out which is the independent variable and which is the dependent variable:

"(Independent variable) *may cause a change in* ***(Dependent Variable)*** *and it isn't possible that* ***(Dependent Variable)*** *could cause a change in* ***(Independent Variable)".***

For example: *"(Amount of sunlight) may cause a change in (plant growth) and it isn't possible that (plant growth) could cause a change in (amount of sunlight)".*

We see that "*amount of sunlight*" must be the independent variable and "*plant growth*" must be the dependent variable because the sentence doesn't make sense the other way around.