# The Scientific Method

## Objective

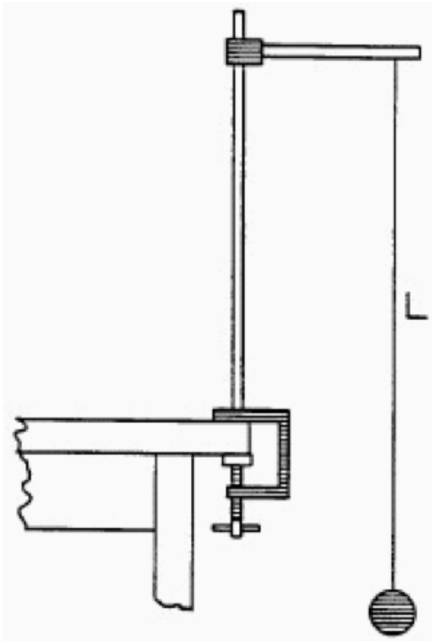
The purpose of this exercise is to apply a systematic approach to a physical problem. A simple pendulum will be used in this particular study. The problem is to determine experimentally whether and how various factors influence the pendulum's period, the time for one complete back-and-forth oscillation. Variables that may or may not affect the period include the mass of the pendulum bob, the length of the string, the amplitude of the angle of swing, and the acceleration due to gravity. The last factor is one over which you have no control. In this study each variable (which you can control) should be isolated and studied individually. Your goal is to write a mathematical expression for the period, $T$, in terms of the variables that affect it.

## Materials

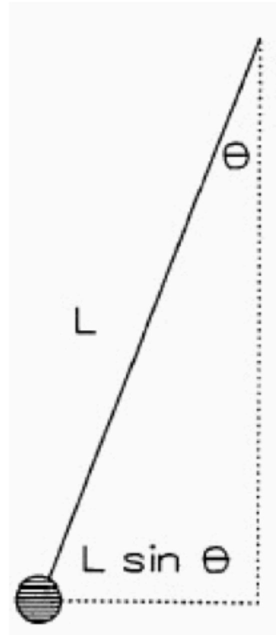
1. 2-meter stick
2. Paper clips
3. Pendulum bobs (box of 12)
4. Protractor
5. Stopwatch
6. String and scissors for room
7. Table clamp and rod (2-m height)
8. Three-hole bracket clamp
9. Triple-beam balance

## Procedure

1. Your apparatus should be set up similar to that illustrated in Figure 1a. First, study the effect of mass. Choose a mass, and suspend it by a light string of known length, say 100 cm. The length of the pendulum should be measured from the point of suspension to the center of the mass. Displace the mass to the side until the string makes some angle, say 5°, with the vertical. After releasing the bob use a stopwatch to measure the time for 20 complete oscillations; compute the period—i.e., the time for one complete (back and forth) oscillation. (In making your time measurement, start and stop the watch at the midpoint in the swing—i.e. the lowest point. Why is this best? And be sure to count "zero" not "one" when you start the watch!) If you release the mass carefully, you should be able to get 20 oscillations without the mass hitting the table. If not, use fewer oscillations, but not less than 10. Repeat the above procedure for the five different masses. Be very careful to keep the length, maximum angle, and other variables the same for all masses so that you are investigating only the effect of mass.




(a) Apparatus




(b) Using sine to determine the angle $\theta$.

**Figure 1**

2. Second, study the effect of maximum angle of swing—i.e. the angle at which the pendulum is released. Keeping length and mass constant, measure the time for 20 oscillations for maximum angles from small values up to 90° (use: 5°, 10°, 15°, 20°, 25°, and 30°). You should do a couple of runs for the 5° and 15° angles. You may use a protractor in determining the angle, or you may find it more precise to use the angle's sine (see Figure 1b), which is the ratio of the lateral displacement to the pendulum length. (This technique is much more accurate.)

3. Third, study the effect of length. Keeping constant the mass and angle of swing (use a small angle—say, between 5 and 15 °), measure the time for 20 oscillations for various lengths such as 20 cm, 40 cm, 60 cm, ..., 140 cm, 160 cm, 180 cm, ... even 200 cm if you can get it reasonably conveniently. (You have to use a wide range of lengths to get any useful data out of this variable, so take several measurements across the entire range from 20 to 200 cm, in increments of 20 cm.)

4. Investigate any *other variables* you can control.

## Determining the Mathematical Relationship

Is the period a function of mass? Of length? Of maximum angle? What is the mathematical relationship in each case? Does any variable have no influence in some range but some influence in another range?

One technique for seeking a mathematical relationship between two variables involves graphing one variable against various powers (or other functions) of the other. For example, if $y$ is directly proportional to $x^1$, the graph of $y$ vs $x$ will be a straight line with equation of the form

$$y = ax + b$$

where $a$ and $b$ are constants; $a$ is the slope (usually represented by "$m$" when mass is not in consideration), and $b$ is the $y$-intercept. On the other hand, if $y$ is directly proportional to $x^2$, the plot of $y$ vs $x$ is a parabola, but the plot of $y$ vs $x^2$ is a straight line with equation of the form

$$y = ax^2 + b$$

Select from your data a variable that influences the period. Plot period vs this variable with other variables held constant. If the plot is not a straight line, try a plot of period vs the square, square-root, or other power of the variable. You will know you have found the right power when the graph is a straight line. (With a little practice you may be able to guess the relationship by considering how period is changed when the variable is changed by a factor of 4, $4^2$ or $4^{1/2}$.) Once you've found which is the linear relationship make sure to state what your constant of proportionality was (your slope). Also, be sure to show all graphs and tables, and circle the graph that you think was the linear relationship. Using these results try to write a mathematical expression for the period $T$ in terms of mass $m$, length $L$, and maximum angle $\theta$. Examples of the kinds of expression you are seeking (the right one is not given) include: $T = \frac{am\theta}{L^2}$ , $T = \frac{bm}{\sqrt{L}}$ , and $T = c\sqrt{\theta}$, where $a$, $b$, and $c$ are constants. Constants can be evaluated by techniques used in analytical geometry. For example, you should be able to get values from the slopes of your straight-line graphs.

## Linear Regression

Now you will more formally determine the best-fit line by determining the values of $a$ and $b$—the slope and vertical intercept—and their uncertainties. Use the methods described in the Linear Regression section of Data Analysis for Physics (PH 22*3) and the tables provided by your instructor.