

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
Physics Department

Physics 8.01T

Fall Term 2004

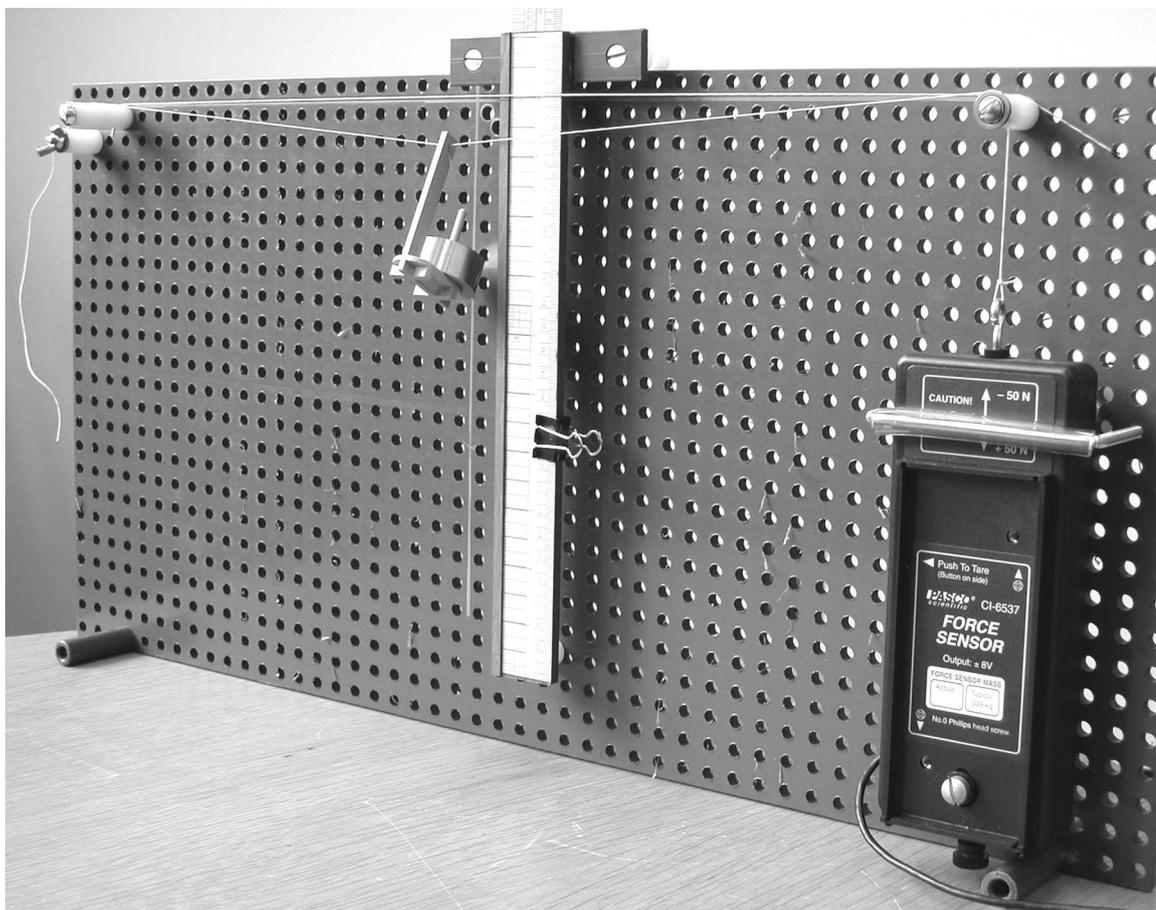
Experiment 05A: Static Equilibrium

Purpose of the Experiment:

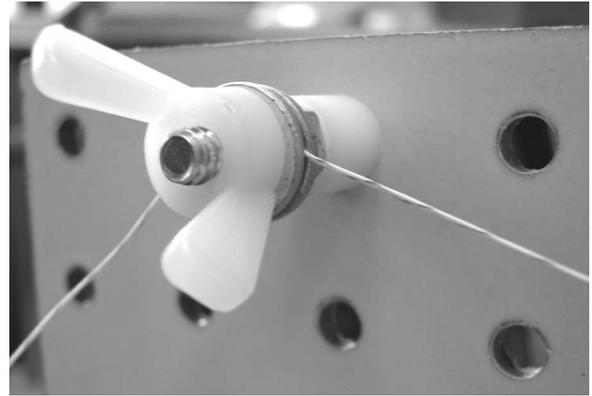
In this experiment you will measure and analyze the forces when bodies are in static equilibrium:

- A weight is suspended from a string that spans the horizontal distance between two horizontal support points. You will measure the tension in the string and see how it depends upon the amount of “slack” in the string. You will plot your results and compare them to the expected mathematical expression.

Suspending a Weight:



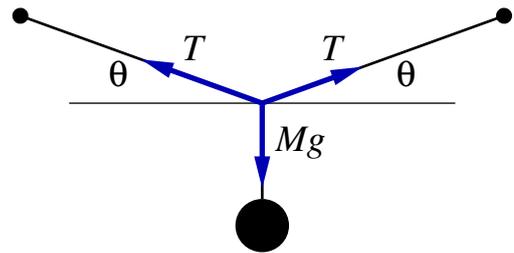
Hang a 100 gm brass weight (brass + holder mass is 105 gm, so weight is 1.03 N) from the center of a string between supports as shown in the photo above.



One end of the string is clamped between two washers so that you can adjust its length. The other passes over a bearing as a low-friction pulley to transmit the tension force to the force sensor. **It is very important for the string to pass over this pulley for all your measurements so that the force will be measured correctly.**

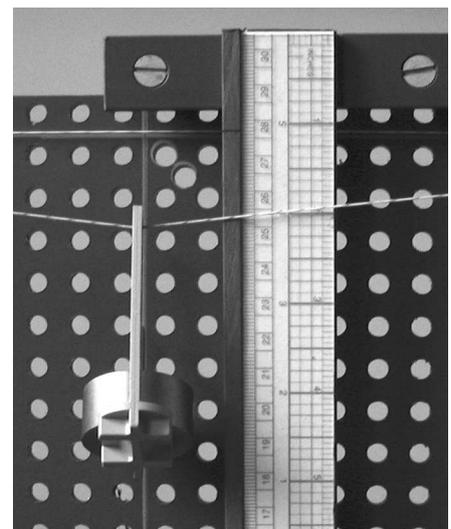
As you can figure out from the free body diagram to the right, when the weight is hung from the middle of the string the two tensions are equal and given by

$$T = Mg/(2 \sin \theta)$$



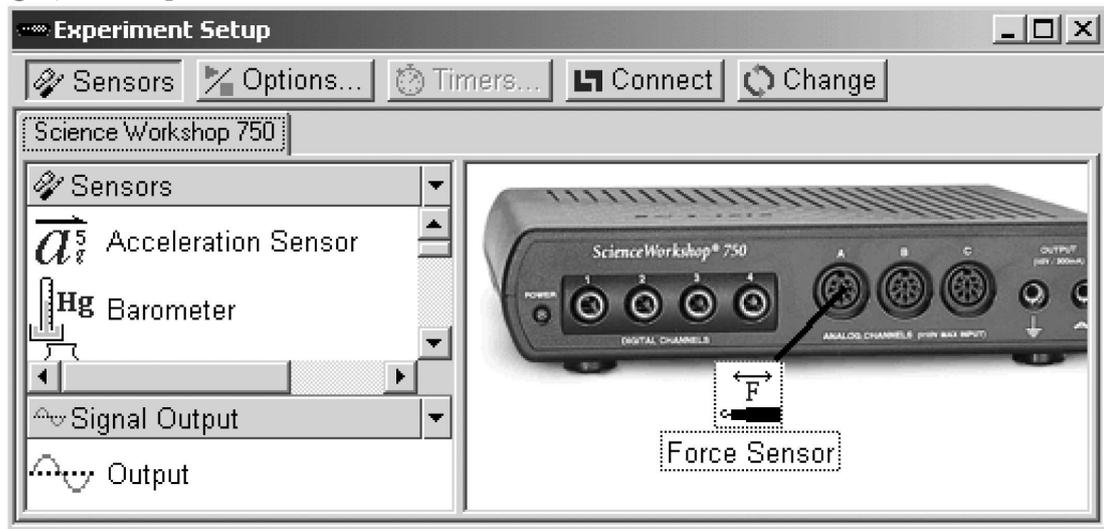
In this experiment you know $Mg = 1.03 \text{ N}$. *DataStudio* can measure the force and calculate $\sin \theta$ for you. Then you will make a plot and carry out a fit to see if you can verify the equation above.

Position the sliding T-square far enough to the right of center so that it does not interfere with the brass weight. Align the right edge of the ruler with the center of a column of holes. As the holes in the board are on $1/2 \text{ in}$ centers, the horizontal distance from the string support point (the pulley) to the ruler will be a multiple of $1/2 \text{ in}$. Keep this same horizontal distance for all of your measurements. A second string (if tight enough) along the top marks the horizontal line between the two string support points. The vertical drop from this line can be measured along the ruler edge.

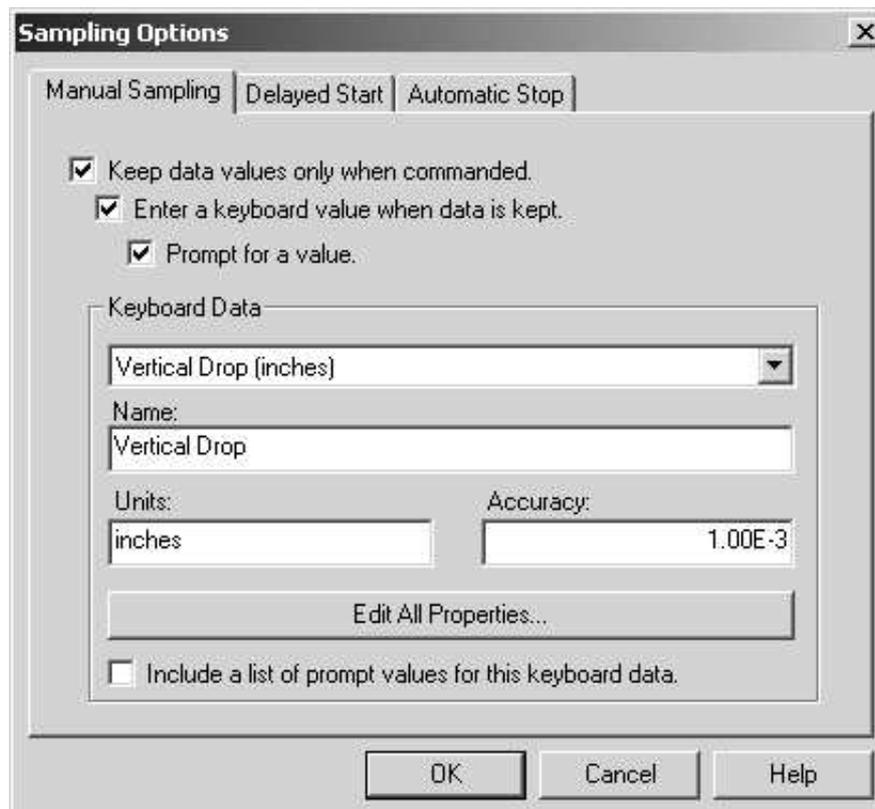


Setting Up DataStudio:

To begin, start up *DataStudio* and connect the force sensor.



Drag the force sensor icon to the interface in the Experiment Setup window. Double-click the force sensor icon to open a window to set the Sensor Properties. Under the “General” tab, choose a sample rate of 10 Hz, and “Slow Force Changes (Spring Tests)”. Under the “Calibration” tab, choose Sensitivity: “Low (1x)”. (The force sensor records force as a negative number when you pull on it.) Next, click the Options button on the Experiment Setup window. That will open another window like this one:



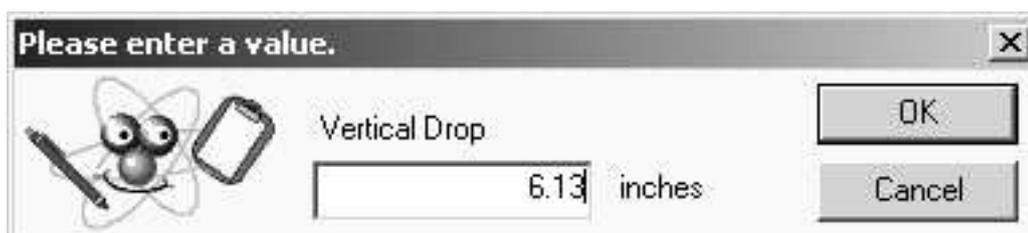
Make sure the top three boxes are checked, then choose “New Keyboard Data” from the pull-down list in the Keyboard Data area. Click the “Edit All Properties” tab; that will open another window which gives you an opportunity to name the variable, choose units for it, and so on—just as you would do if entering data into a table. Choose the variable name, such as **Vertical Drop**, and the units (inches).

After you click OK on the Manual Sampling Options window, a new entry with the name you chose for your variable (e.g., “Vertical Drop (inches)”) should appear in the Data window. You are now ready to begin measurements.

There is no need to calibrate the force sensor, but you must tare it before starting your measurements by pressing the tare button on it when there is no force applied to it. You might also want to set up a Meter display so you can see what the force sensor readings are; to do that, drag the force sensor entry in the Data window onto the Meter entry in the Displays window.

Hints: if you measure the vertical drop with a ruler divided into 1/8, 1/16 inches, and so on (be careful, some rulers may have 1/10 inch divisions) you will have to convert them to decimals before typing them into the window. You could avoid that hassle by expressing the horizontal distance to the pulley support in mm (1 in is 25.4 mm), put the mm scale of the ruler along the right edge of the T-square, and do all your measurements in mm instead of inches. It will also be easier if you slide the ruler up or down so that an even inch (or cm) marker lines up with the horizontal line between the supports. To minimize parallax error, try position your eye so your line of sight is perpendicular to the board whenever you align or measure things.

Adjust the string length so the weight is low (close to the table top). When you click the Start button, it will change to a “Keep” button, a stop button with a red square in it will appear beside it, and the force will be displayed on the meter. Before every measurement **make sure the string is on the pulley**, as illustrated on the second page. When you have measured the vertical drop, click the Keep button. That will cause *DataStudio* to record the force and open up a window like this one:



Type your measured vertical drop into the window and click OK. Loosen the wing nut clamp, shorten the string, re-position the weight in the middle of the string, and repeat the process. Do this for nine or ten different string lengths, including two or three where the string is so tight that the suspension point of the weight is less than 1.25 in below the horizontal line between the suspension points. To get these points, you will have to have some tension in the string even when the weight is not hung on it. (That is because the string stretches; the measured force will still be correct when the weight is suspended.) Also, measure the lengths carefully when θ is small, in order to get a good value for $\sin \theta$.

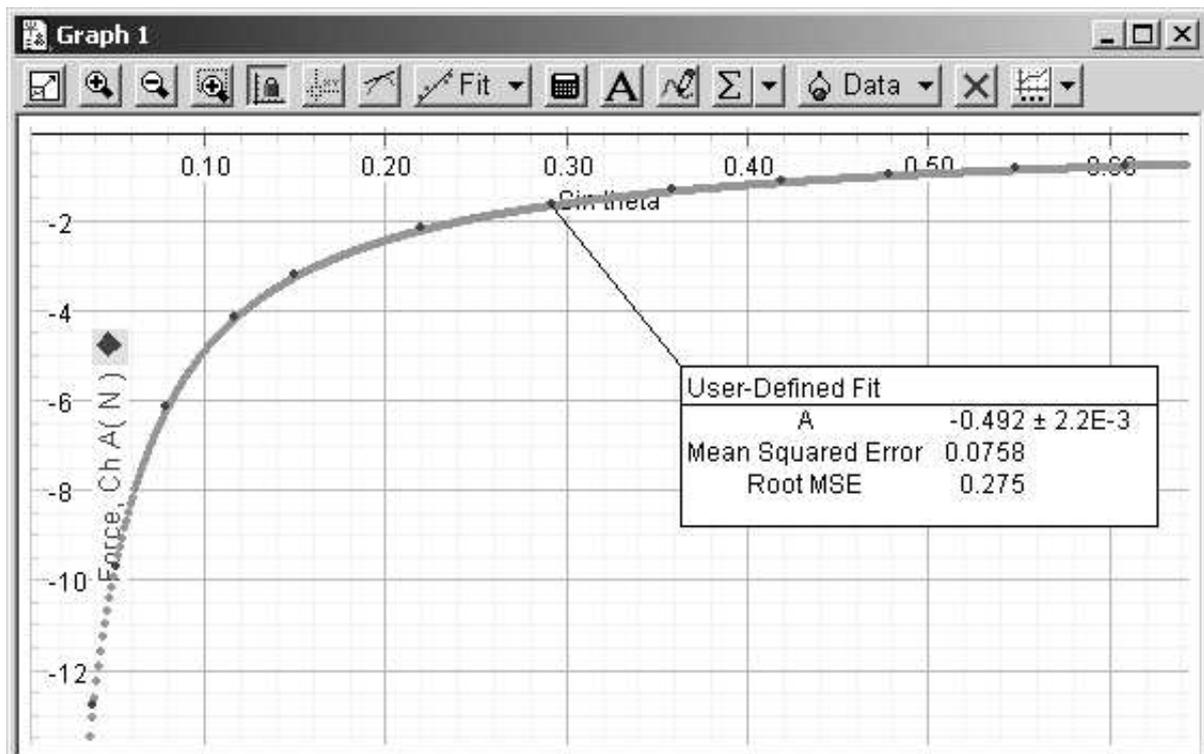
When you have taken the measurements you want, click the red stop button.

You will now have two data sets in the Data window. One will be the force measurement, and the other will be the values you typed in for the vertical drop; both will be identified by the same run number. They are both dependent variables (the independent variable in each case is the time of the measurement), so you can do calculations on them.

To calculate $\sin \theta$, click the Calculate button up by the timer window. That will open a Calculator window. Type $\text{Sin theta} = \sin(\arctan(x/H))$ in the definition window. (Replace “H” by the horizontal distance between the edge of your ruler and the pulley; in my case H was 8.0 in.) Under the Variable pull-down menu check “Data Measurement”; that will open another window that allows you to choose your “Vertical Drop” variable. After you click Accept, there should be an entry labeled “Sin theta = $\sin(\arctan(x/8.0))$ ” in the Data window. Again, this is an independent variable with the measurement time as the dependent variable.

The force sensor records force as a negative number when you pull on it. That is not a problem, but if you’d rather see the tension as a positive number, you can do a calculation on the force data ($\text{Tension} = -1 * x$) to change that.

Now you are ready to analyze your data. What you want is a plot of the force (or tension) along the Y axis and $\sin \theta$ along the X axis. To get it, drag your force data onto “Graph” in the Displays window. That will make a graph with force on the Y axis and measurement time on the X axis. Next, drag your “Sin theta” data from the Data window onto the X axis of the graph you just made (make sure that the dotted line appears only around the X axis, and not around the entire graph, before you release the drag). That should give you a graph like this one.



The next step is to fit a function to your data.

From analysis of the free body force diagram we expected $T = Mg/(2 \sin \theta)$, so fit a function of the form $T = A/\sin \theta$ to the data. *DataStudio* has an Inverse Fit function, but it includes a background term, which we do not want. So, a User-Defined Fit is required. Make that choice on the graph and type the definition $y = A/x$ in the Curve Fit window. (If you don't get the Curve Fit window right away, double-click either the User-Defined Fit entry in the Data window or the text box that appeared in your graph.) After you click Accept to do the fit, you should get something like the fit line on my graph. (I had 12 data points corresponding to $0.04 \lesssim \sin \theta \lesssim 0.6$ and $0.6 \text{ N} \lesssim |T| \lesssim 13 \text{ N}$.)

To see how well your measurements follow the prediction, you can look at the graph, and you can be more quantitative by using the Root MSE (remember, because of the *DataStudio* bug, you should divide it by the square root of the number of points in the fit—in my case that was 3.5). So my RMS error was about $\pm 0.08 \text{ N}$. The accuracy of the force sensor is a bit better than that, but when I include the uncertainty in $\tan \theta$ from my measurements the experiment certainly seems consistent with the predicted behavior. (You will explore this idea quantitatively in your report.)

There will be a problem related to this experiment in problem set 05; it is also attached as the last page of this document.

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Part of Problem Set 05

Section and Group: _____

Your Name: _____

You may work together as a group to solve this problem, but each group member should turn in a copy of this answer with problem set 05. If you like, just fill in the information above, complete this page, and attach it to your homework solutions.

Suppose a rope is tied rather tightly between two trees that are 30 m apart. You grab the middle of the rope and pull it perpendicular to the line between the trees with as much force as you can. Assume this force is 1000 N (about 225 lb), and the point where you are pulling on the rope is 1 m from the line joining the trees.

1. How much is the force tending to pull the trees together?
2. Give an example where you think this might be of practical use.