Relationship between pendulum length and period - using a motion sensor

Technician and teacher sheet

Apparatus

A wireless motion sensor.

Retort stand and clamp.

Small clip (crocodile clip or binder clip).

Pendulum mass (tennis ball, punctured)

String

Ruler

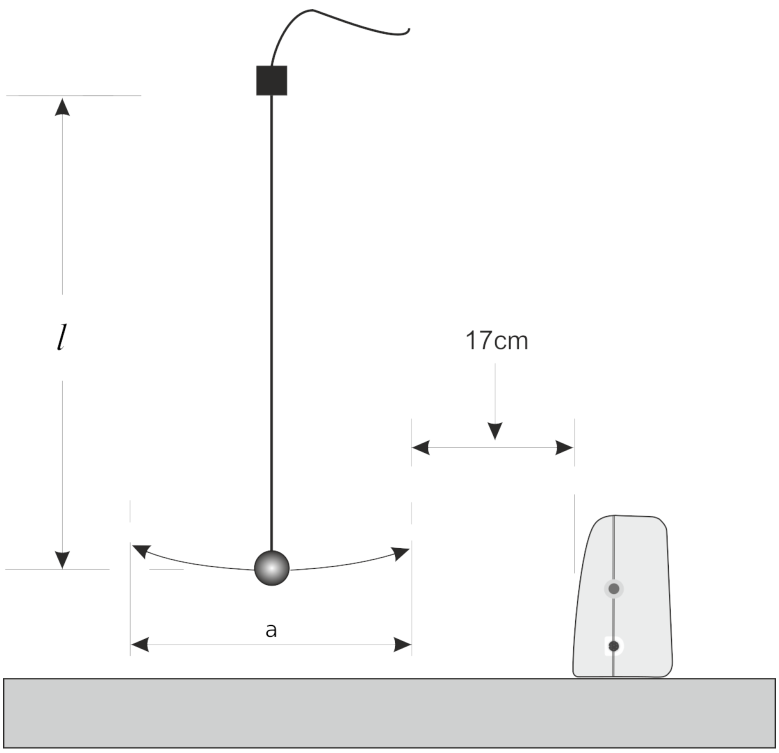
Data recording setup.

Select Start to begin, stop after duration.

Intersample to 10ms

Sensor range set to 1.5m

After initial set up use a trigger to start recording when distance rises above (static distance + 10cm)



The relationship between pendulum period and the length of the pendulum is for many counter intuitive, so much so that this investigation has been used as part of the CASE (Cognitive Acceleration in Science Education) scheme. In a CASE investigation there is a deliberate conflict created between the results and the expectation. With a pendulum most people see the bob swinging more quickly as the period increases and therefore assume the time for the swing is getting faster.

The time taken for a number of swings can be measured and the time for a single swing calculated. Problems arise with the accuracy of the timer (both man and machine) and these become more exaggerated as the length of the pendulum becomes shorter. The errors can be enough to hide the relationship between period and length.

Using a Motion sensor provides a more complete picture of the pendulum swing. The data shows the change in distance against time. The time of the swing can be easily found using the interval tool; the student will need to think about which interval to measure. The graph formed shows a sine wave, the creation of a smooth wave shape from a back and forward motion can be a valuable teaching step. The visual conversion of a change of distance into an “up and down” sine graph makes the use of the Motion sensor worthwhile.

If it can be arranged a demonstration of a really big pendulum is useful in setting the scene, a large ball suspended from string (rope) connected to the ceiling or in a stairwell makes a dramatic starting point.

Practical notes.

You can use any pendulum bob, as long as the motion sensor can pick it up reliably, experience says that small metal bobs may be prone to data misses. Our preferred bob is a 4.5 inch spherical ballcock float. The float can be filled with sand or water to increase the mass (the screw hole will probably need drilling out to allow filling)

Assemble the apparatus as shown. Make sure that the pendulum can swing freely and that there isn't anything in the way that the Motion sensor can detect apart from the pendulum bob.

Position the Motion sensor 0.3 m from the front of the bob when hanging at rest (this will be zero metres of displacement). The distance from the 0m displacement point to the the sensor can be used to trigger data collection when the distance value rises above 0.1 m.

To set the trigger correctly, use rises above and draw the bob away from the motion sensor and release to let it swing towards the sensor and then away. The trigger will be activated as the bob moves away from the sensor after it has passed through the centre of its oscillation. Try to release the bob from the same position to keep the amplitude as similar as possible

The ‘pendulum bob’ should be level with the lower edge of the sensor transducer when it is stationary, it was found that a support to match this height was useful to realign the position when the pendulum length was changed. Something like a plastic cup cut to height is ideal. When changing height, rest the bob on the cup to get the correct position of the lower edge.

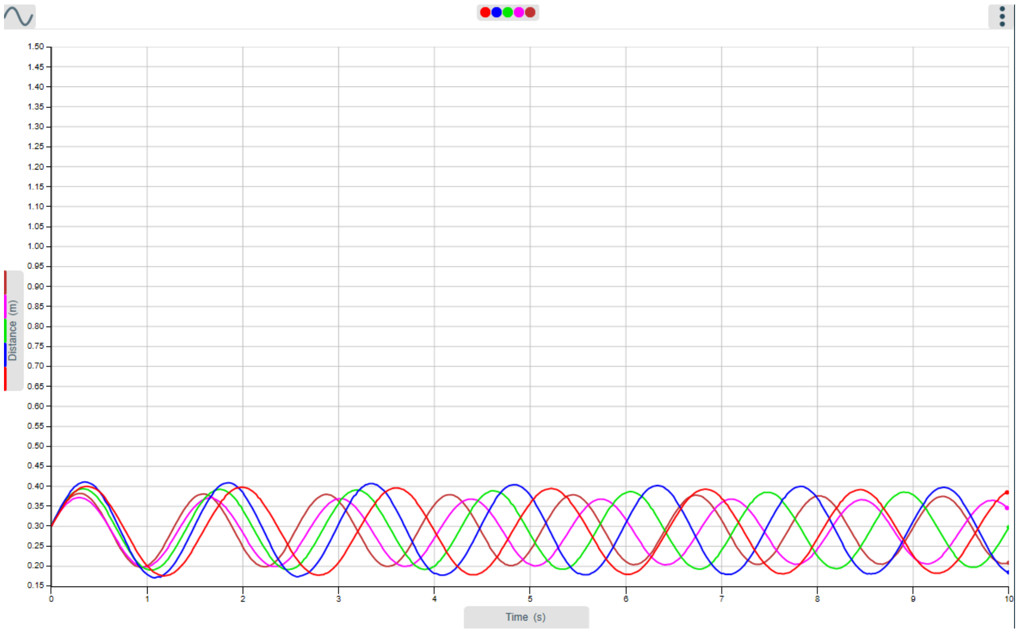
The bob of the pendulum should not go above the top of the sensor element at the highest point of the swing. The value of “a” needs to be about 20 cm, this may take a little refinement (the motion sensor technology can be affected by the room and the smoothness of the bob)

Use a starting value for ‘l’ (the length of the pendulum) of about 0.9 m

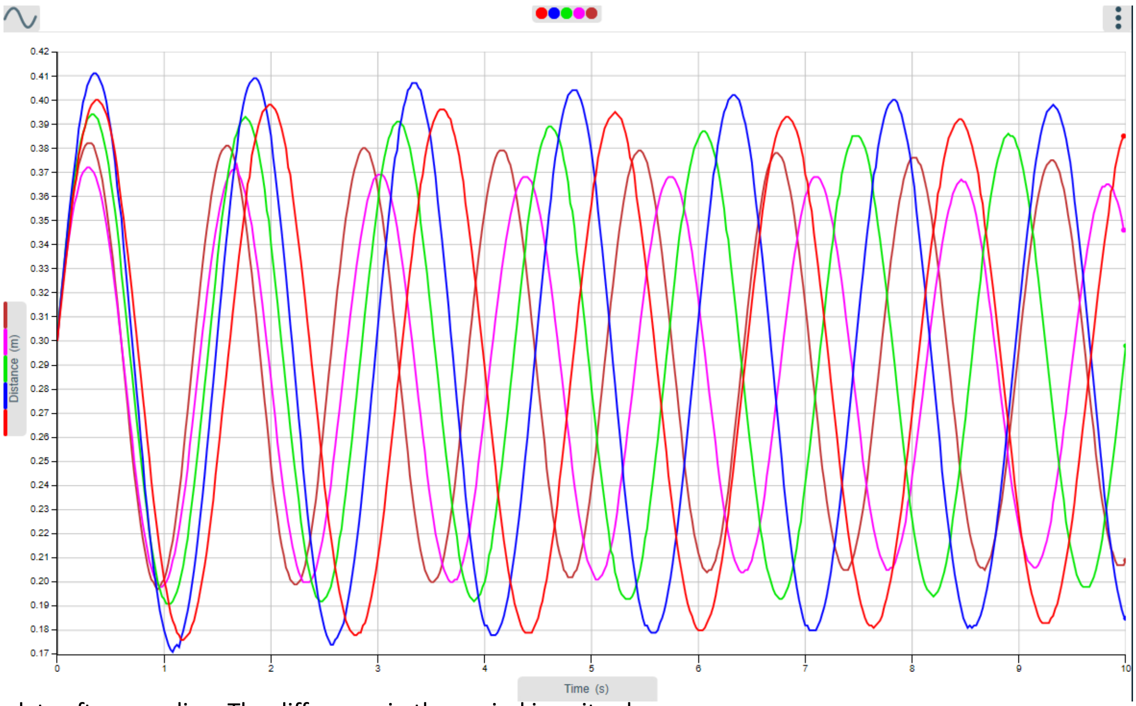
In a perfect demonstration the “string” connecting the pendulum bob to the clamp should be as fine as possible and with a degree of stiffness; fine fuse wire makes an ideal “string”. At this level fine cotton will be adequate however.

Hardware limitations: The fastest speed the sensor can be used to collect data is fixed by the frequency at which the unit transmits its ultrasound pulses, the software allows 10ms intersample as the shortest intersample. Use 10 ms intersample to start with, if necessary reduce to 20 ms intersample. Anything longer than 20ms will impact on the data points defining the sine wave being produced.

IMPORTANT: Be aware of the size of the ultrasound cone, at one metre from the Motion sensor the cone will have a diameter of 0.2 m, at 2 metres it will be 0.4 m.



Example of data as collected with 5 different pendulum lengths



Sample data after rescaling. The difference in the period is quite clear.

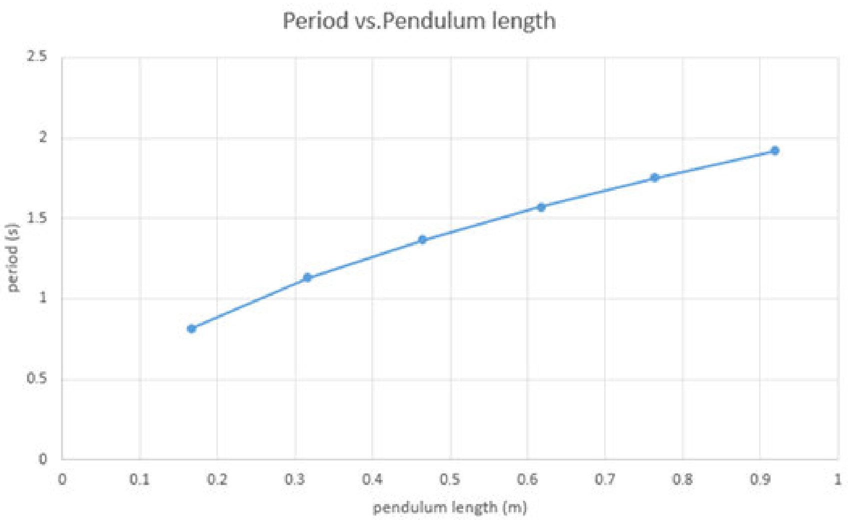
Use the coloured dots at the top of the graph to turn on and off runs of data and use the difference tool to work out the period of each pendulum length.

The students will need to tabulate the pendulum length, time for 5 oscillations (and hence the period T), Log l and log T.

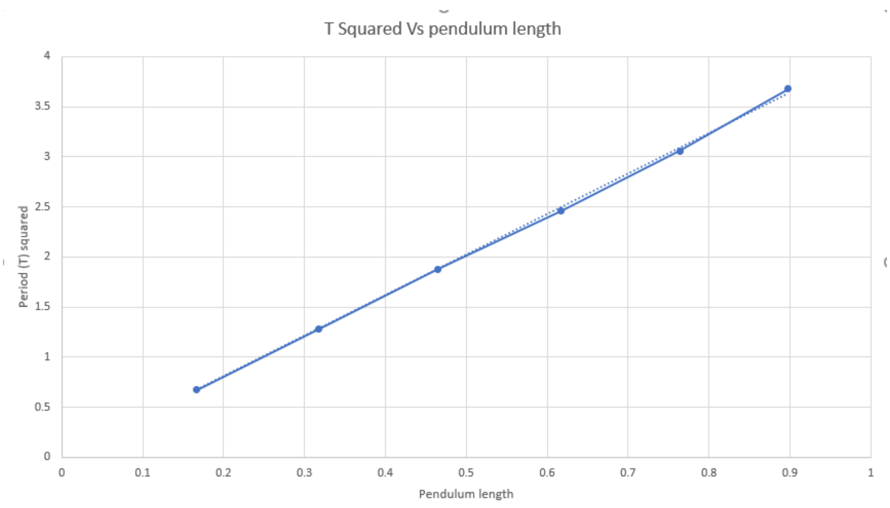
A simple plot of period (y axis) vs. pendulum length (x axis) will give a slightly curved plot line. The plot of Log Period (T) (y axis) vs. Log pendulum length (l) (x axis) will give a linear plot showing the linear relationship between period and length.

A spreadsheet will allow the students to plot the necessary graphs and to create the log data.

Results T vs. l			
Pendulum length (T) (m)	Time for 10 oscillations	Period T (s)	T^2
0.898	19.20	1.92	3.68
0.764	17.52	1.75	3.06
0.617	15.70	1.57	2.46
0.465	13.68	1.37	1.88
0.317	11.13	1.13	1.28
0.167	8.18	0.82	0.67

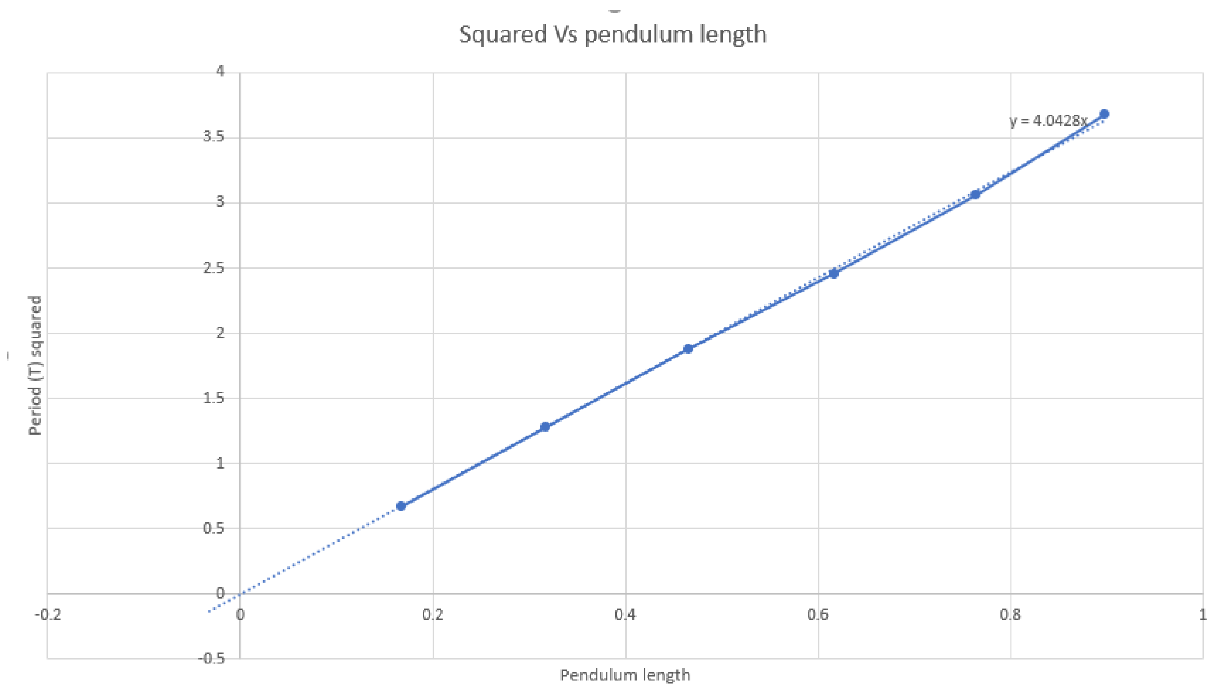


Plot of period (T) vs. pendulum length (l)



Plot of period (T^2) vs. pendulum length (l)

The relationship between pendulum length and period is clearly seen.



The best fit line extends back through the 0/0 point. As it should, when pendulum length is 0 there can be no pendulum swing.

You can do a quick check of the data, the gradient of the line should be equal to,

$4\pi^2/g$ = (4.023)

This data, using the trend line facility in excel gives a value of 4.0428, which is very close. It will have a small effect if g is calculated.

Software knowledge required.

- Connect sensors to the software.
- Change intersample period.
- Select and deselect ranges on sensors.
- Use settings to set up a trigger (rises above)
- Scale data.
- Change axis from unified to separate for each data type.