Physics Education Program

Name: ____________________

Teacher: ____________________

School: ____________________

Vertical Accelerometer

student activity

Key Ideas

Acceleration, Accelerometer, Force, Graphing, Gravity, Hooke's Law, Mass, Spring constant, Weight

Equipment

Small spring or elastic
Standard mass set (10 or 20g)
Retort stands
Retort stand clamps
1 metre ruler
Strong sewing elastic for wrist strap
Five fishing sinkers (~100-120g)
Paper clips
Coloured electrical tape or permanent marker pen
Scissors
Electric drill (2-3mm drill bit)
Nylon fishing line
Graph paper, note pad, pencil, eraser, calculator

This activity should be completed before you visit Dreamworld.

Standard Achieved: Scientific Techniques and Scientific Investigation

VHA	HA	SA	LA	VLA	Not Attempted
• identifies and applies risk management procedures	• identifies and applies safety procedures	• applies safety procedures	• follows safe practices	• follows safety instructions	• not attempted
• systematically analyses primary and secondary information showing links to underlying concepts	• analyses primary and secondary information recognising underlying concepts	• analyses primary and secondary data and information	• analyses primary and secondary data and information to a limited extent	• describes data and information	• not attempted

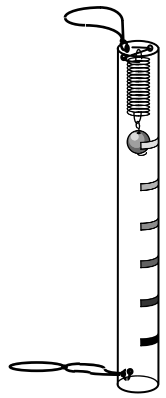
Laboratory Activity: Hooke's Law and the Spring Constant

Objectives

1. To determine the spring constant k of the spring to be used in the vertical accelerometer.

2. To plot and interpret the graph of spring extension versus applied mass.

3. To select the appropriate mass used in the vertical accelerometer to measure accelerations of up to 4.5 g.

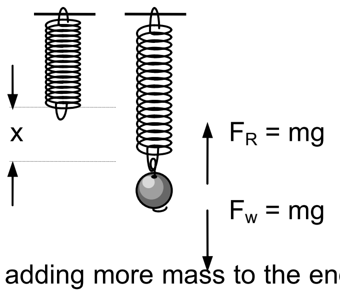


A Vertical Accelerometer

Introduction

At Dreamworld, you will experience accelerations of up to 4.5 g. This means you will effectively feel 4.5 times your normal weight! You will use vertical accelerometers to measure these accelerations. These accelerometers employ springs or elastic and a small mass to provide a direct measure of your acceleration.

Springs and elastic stretch in a linear fashion as the force on them is increased. The simple relationship between spring extension and load is known as Hooke's Law. It is simply a mathematical way of saying that for equal increases in the load (or force) applied, there is a proportional increase in the extension of the spring:

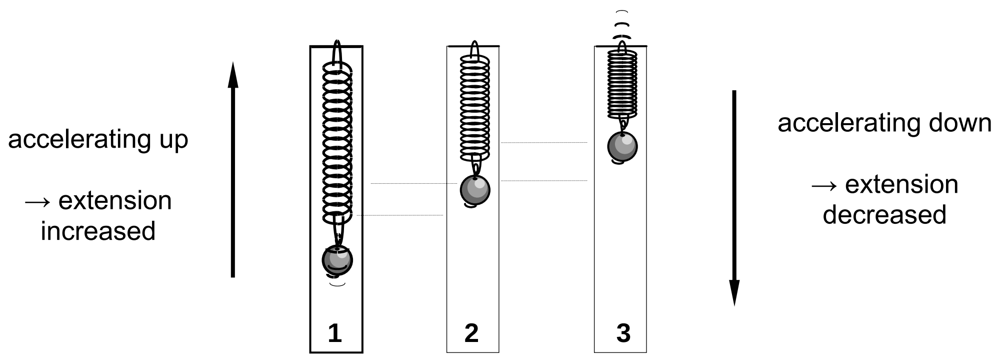


$$\mathbf{F_R} = \mathbf{k\,x} \qquad \textit{Equation 1}$$

where

$\mathbf{F_R}$ = restoring force (= F_w)
k = the spring constant
x = spring extension

By adding more mass to the end of the spring, there will be an increase in extension of the spring. Similarly, if the spring is accelerated up or down as illustrated below, the deflection of the spring will increase or decrease proportionally. Later, you will make your own accelerometer and calibrate it for use on the attractions at Dreamworld.



Three cases for accelerometer spring deflection

1. Accelerating up, 2. sitting still, and 3. accelerating down.

The concept of the vertical accelerometer is quite straightforward. We can describe the concept mathematically and derive an equation for the acceleration in terms of spring deflection. By combining and rearranging equation 1 with Newton's 2nd Law we get,

Newton's 2nd Law $$\mathbf{F = m\,a}$$ *Equation 2*

$$\mathbf{F_W = F_R}$$

$$\mathbf{m\,a = k\,x}$$

rearranging, we obtain

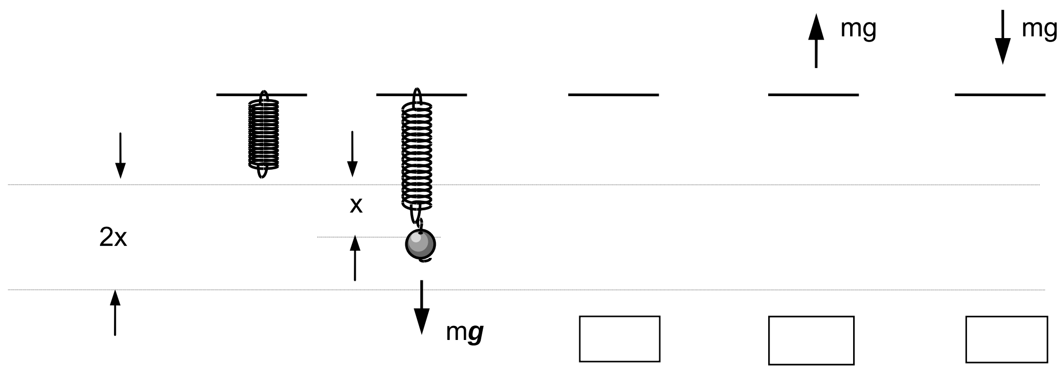
$$\mathbf{a} = \frac{\mathbf{k\,x}}{\mathbf{m}}$$ *Equation 3*

Exercise 1

Consider the cases below. Complete the table by entering the values for the restoring force and spring deflections in the boxes. Below the table, draw what the spring would look like.

Restoring force under various conditions

	No mass	**One mass**	**Two masses**	**One mass accelerating up**	**One mass accelerating down**
Mass m	0	*m*	2*m*	*M*	*m*
Acceleration a	0	0	0	g *up*	g *down*
Restoring Force F_R	0	*m*g	2*m*g		
Deflection x	0	x			

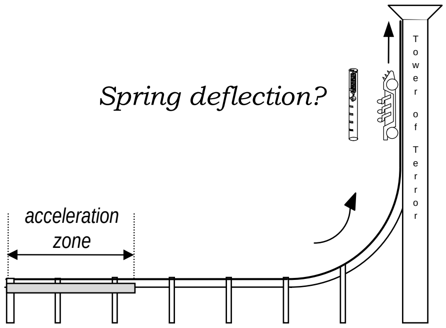


Question: How much will an (a) 120g, (b) 220g and (c) 320g sinker effectively weigh when accelerated at 4.5g? (d)How much will you effectively weigh?

Challenge Question

The Tower of Terror launches you along a horizontal track which curves into a vertical section over 39 stories high. No more acceleration from the drive system is applied to the car after it leaves the acceleration zone. With the accelerometer held vertically (parallel to the tower) what will the spring deflection be as the car travels ***up*** *the tower?*

You can try this and check your answer at Dreamworld!

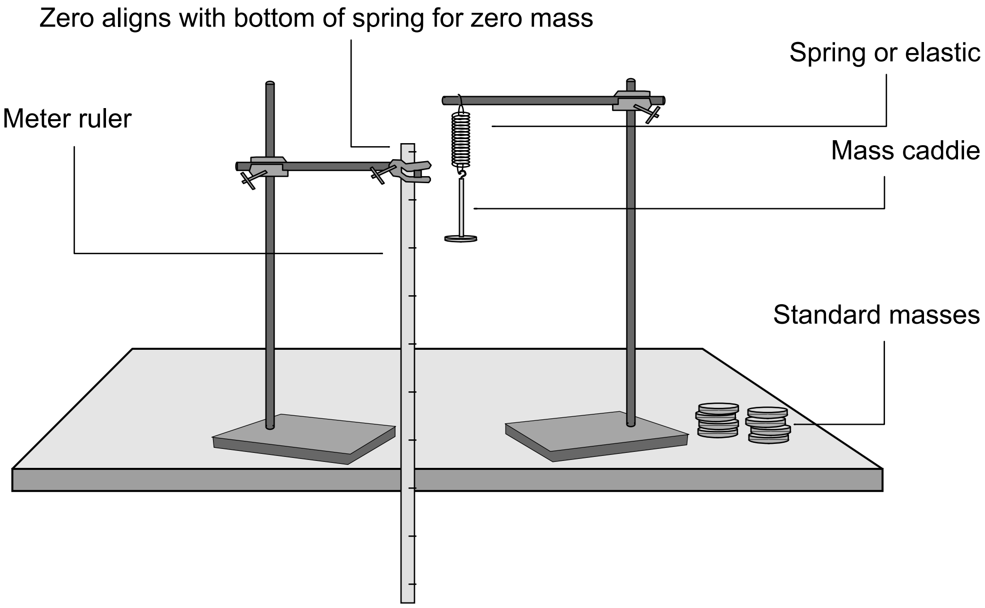


Procedure

This is the procedure for determining the spring constant **k**, from a graph of spring deflection versus applied mass. You will later use the spring constant to calibrate your vertical accelerometer.

Set up the apparatus as illustrated below but without the mass caddie attached to the spring. Before suspending the mass caddie, adjust the ruler so that the zero aligns with the bottom of the spring.

Suspend the mass caddie alone and record the spring deflection and mass in a table. Add 10g or 20g masses to the spring and measure the deflection as each new mass is added. To ensure the spring or elastic is not overloaded, plot the extension after each mass is added on a rough graph of deflection versus applied mass. When you notice that new points do not lie on the straight line (as illustrated on Graph 1 on the next page), the spring's nonlinear region has been reached. *Do not continue adding masses after this point is reached as this may result in damage to the spring or elastic.*



Experimental apparatus for measuring spring constant

Mass (g)	Extension (cm)

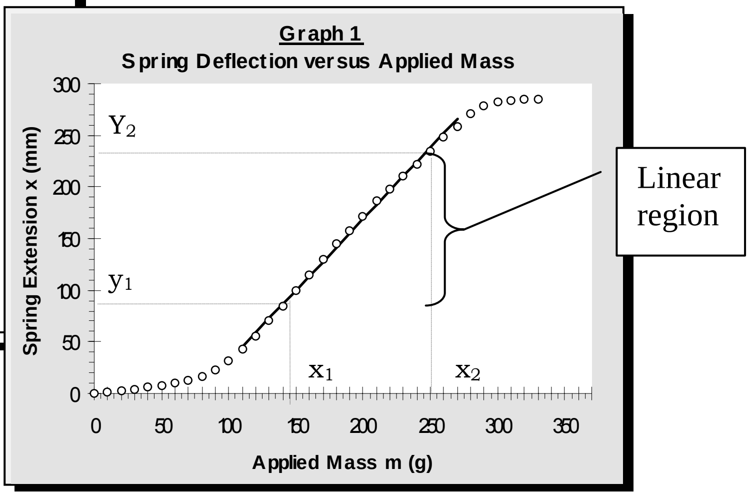
Results

Carefully plot the spring deflection versus applied mass on graph paper. Be sure to label the axes, including the units, and clearly title your graph. The linear region of the data are to be used for the calculation of the spring constant as described in the following section. Your graph should be as accurate as possible.

Analysis

Table 1: Spring extensions for applied mass (Spring length is 70 mm)

Applied Mass m *(g)*	Measured Spring Extension x *(mm)*	Percentage Extension (x/X)
0	0	0%
20	2	3%
40	6	9%
60	10	14%
80	17	24%
100	32	46%
120	56	80%
140	85	121%
160	115	164%
180	145	207%
200	172	246%
220	196	280%
240	222	317%
260	246	351%
280	271	387%
300	282	403%
320	285	407%



Now use your graphics calculator to determine the equation of the linear region of your graph.

Alternatively, you can use the following procedure to compare the standard formula for a straight line (y = mx + c) with the equations of the graph you drew of spring deflection versus applied mass.

$$\boldsymbol{y = mx + c} \qquad \textit{Straight line equation}$$

$$x = \frac{g}{k}m \qquad \textit{Equation 3 rearranged, with acceleration g.}$$

On your graph, you plotted the mass **m** on the ***x*** axis and spring deflection **x** on the **y** axis. (*Be careful not to confuse the symbols here*!) The slope of your graph is given by

$$\textbf{slope } \boldsymbol{m} = \frac{\mathbf{g}}{\mathbf{k}}$$ *Note that "m" in italics here represents gradient or slope.*

and so

$$\mathbf{k} = \frac{\mathbf{g}}{\textbf{slope } \boldsymbol{m}} \qquad \textit{Equation 4}$$

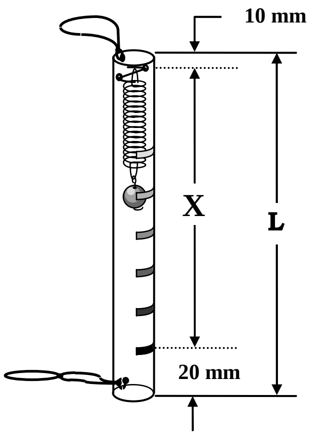
The slope can be calculated using equation 5.

$$\textbf{slope m} = \frac{\mathbf{y}_2 - \mathbf{y}_1}{\mathbf{x}_2 - \mathbf{x}_1} \qquad \textit{Equation 5}$$

Hence, to determine the spring constant **k**, first find the slope of your graph using your graphics calculator or equation 5 above. Then enter your slope into equation 4. The value you calculate with equation 4 is the spring constant **k** of the spring or elastic you will be using in your accelerometer.

Designing your vertical accelerometer

Now that you know the spring constant of the spring you will be using, you can design your vertical accelerometer which you will use at Dreamworld. Use the following procedure to select the combination of spring length and mass for your accelerometer.



L = length of accelerometer tube
x = length of spring
X = maximum deflection of spring
m = mass of sinker

You need to ensure that even with an acceleration of 5g, the sinker does not protrude from the bottom of your accelerometer tube. Allow for the length of your spring **x**, plus 10 mm (0.01 m) at the top of tube, and 20 mm (0.02 m) at the bottom. The maximum deflection of the spring, **X** (metres), at an acceleration of 5g should be:

$$\mathbf{X} = \mathbf{L} - (0.01 + 0.02 + \mathbf{x}) \qquad \textit{Equation 6}$$

Measure the length **x** of your spring when it is lying horizontally, and the length of your accelerometer tube, and use equation 6 to calculate **X**.

For a 5g acceleration equation 3 gives the spring extension as:

$$\mathbf{k\,X} = \mathbf{m} \times \mathbf{5\,g} \qquad \textit{Equation 7}$$

Rearranging equation 7, we can calculate an appropriate value for mass of the sinker, **m**, as follows:

$$\mathbf{m} = \frac{\mathbf{k\,X}}{\mathbf{5\,g}} \qquad \textit{Equation 8}$$

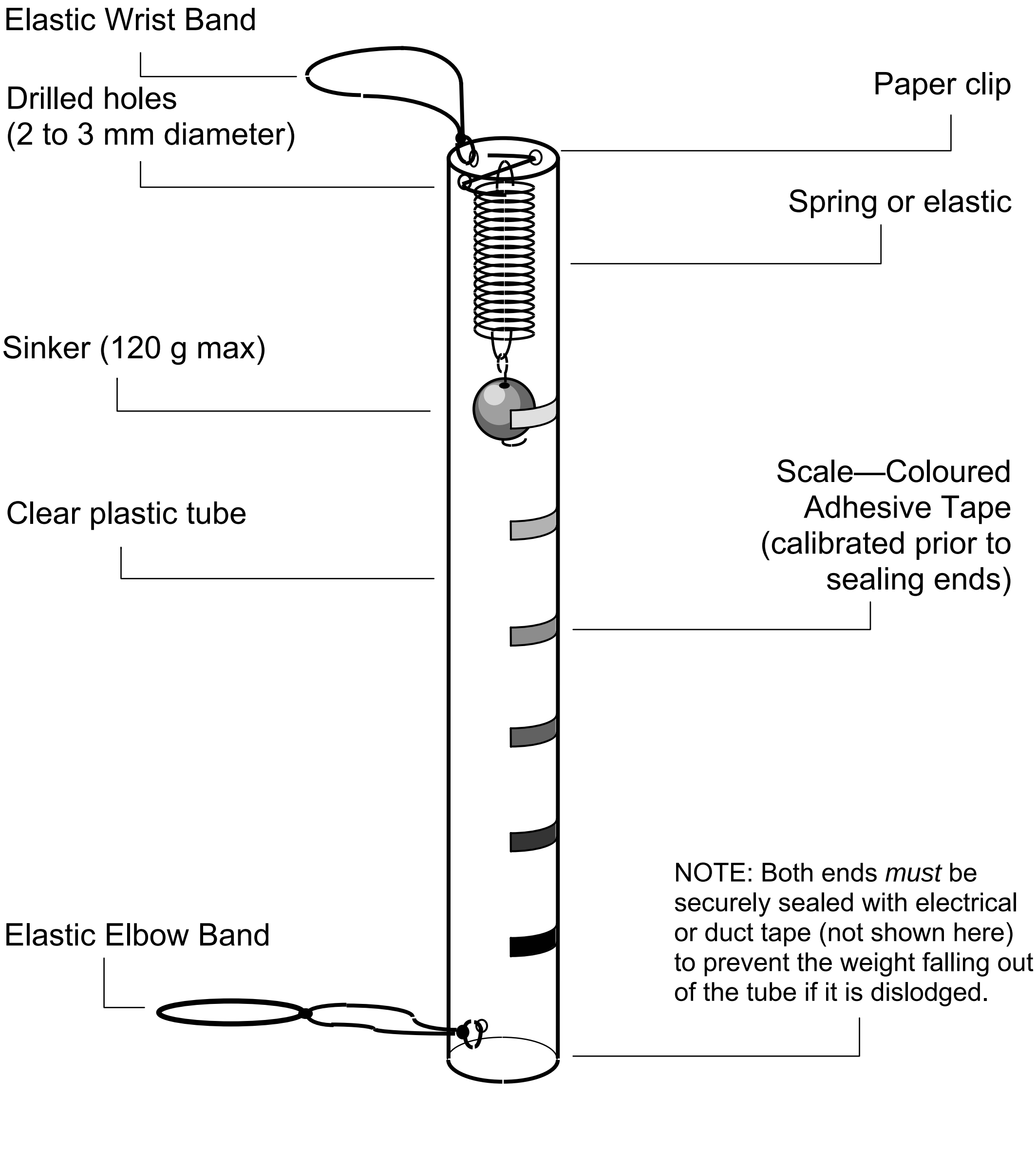
Substitute your values for **X** and k into equation 8 to calculate the mass of sinker that you should use. If the value you obtain is more than 120 g (0.12 kg), you will need to shorten your spring or elastic so that your accelerometer is not too heavy.

Remember, at 4.5 g, objects seem to 'weigh' 4.5 times more than usual – so a 200 g sinker would 'weigh' 900 g—that's almost 1kg!

Once you have selected an appropriate mass, use the following procedure to build your vertical accelerometer to use on your excursion at Dreamworld.

Vertical Accelerometer Assembly

As a safety check, prior to assembly, ensure that the combination of the spring and sinkers is configured such that the spring deflection of 5 suspended masses does not exceed the length of the tube. This can be performed easily by trial and error or a more systematic approach can be used as a lab exercise.



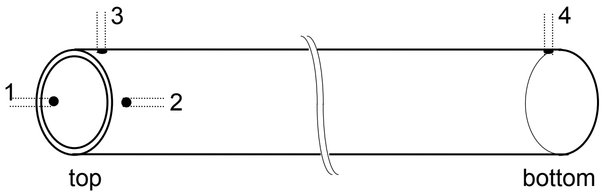
A completed vertical accelerometer (sealed ends not illustrated)

Assembly Instructions

Before you begin

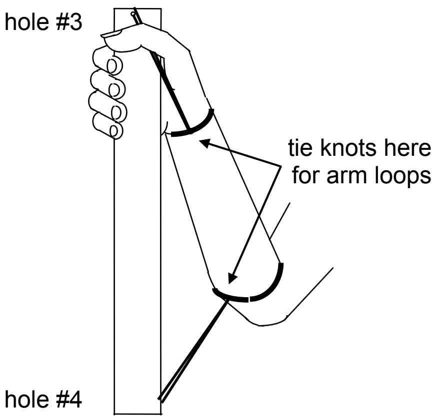
- Ensure the combination of the spring (or elastic) length and sinker mass you have selected will allow measurement of accelerations up to 5***g*** (i.e. the full scale deflection, *FSD,* of your accelerometer will be 5***g*** or 49 ms^{-2})
- Have all the materials and equipment ready, including five identical sinkers for calibration of the accelerometer at Step 7
- Read through the instructions before beginning

Step 1



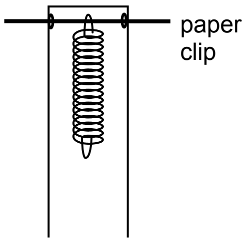
Drill three 2mm holes at the top of the tube and one at the bottom as illustrated

Step 2



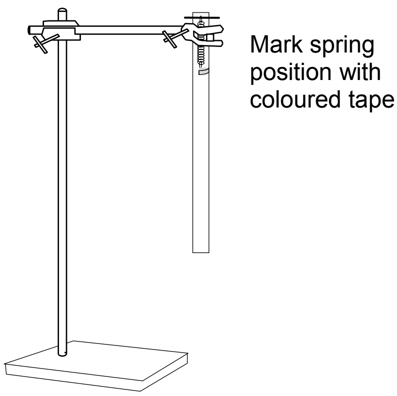
Attach braided elastic straps through holes 3 and 4 using secure knots. The tube will be held vertically as illustrated while riding.

Step 3



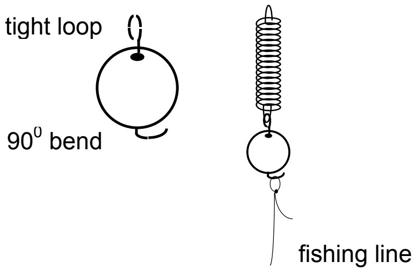
Suspend the spring inside the tube using a straightened paper clip. *(The spring needs to be removed before completion so don't bend the paper clip at this stage).*

Step 4



Set the tube with the spring suspended inside vertically in a lab stand as illustrated. Mark the position at which the bottom of the spring hangs on the side of the tube using a thin strip of coloured electrical tape or a permanent marker pen. This mark corresponds to an acceleration of 0***g*** (i.e. weightless).

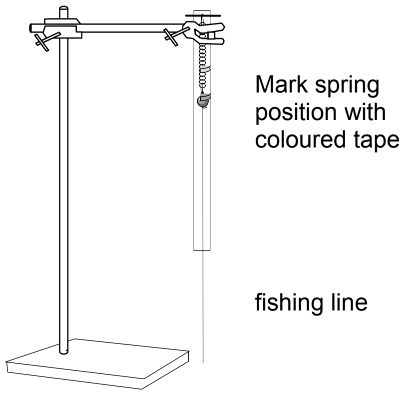
Step 5



Remove the spring and use a straightened paper clip to secure the sinker onto it as illustrated.

Attach nylon fishing line to the bottom of the sinker as illustrated. *Ensure that the length of fishing line is longer than the tube.*

Step 6

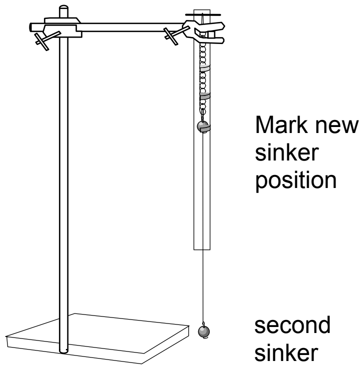


Suspend the spring back in the tube and reset it in the lab stand as in Step 4.

NOTE: The fishing line should be protruding from the bottom of the tube.

Mark the position at which the sinker is hanging using a different colour of electrical tape or permanent marker pen. This mark corresponds to an acceleration of 1***g***.

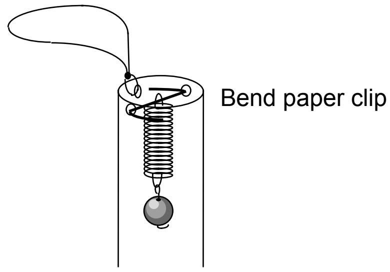
Step 7



Suspend a second, identical sinker onto the fishing line. Mark the new position of the *first* sinker. This mark corresponds to an acceleration of 2***g***.

Add a third sinker and mark the position of the first sinker on the tube corresponding to 3***g***. Repeat this procedure until you have reached five sinkers—*a total of six markings*

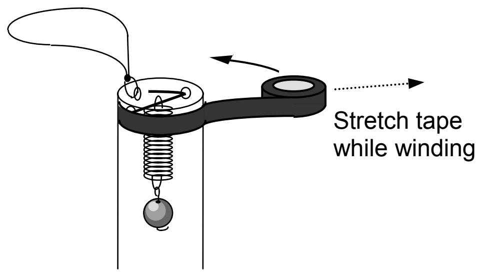
Step 8



Remove the additional sinkers and fishing line and reinstall the spring and single sinker in the tube.

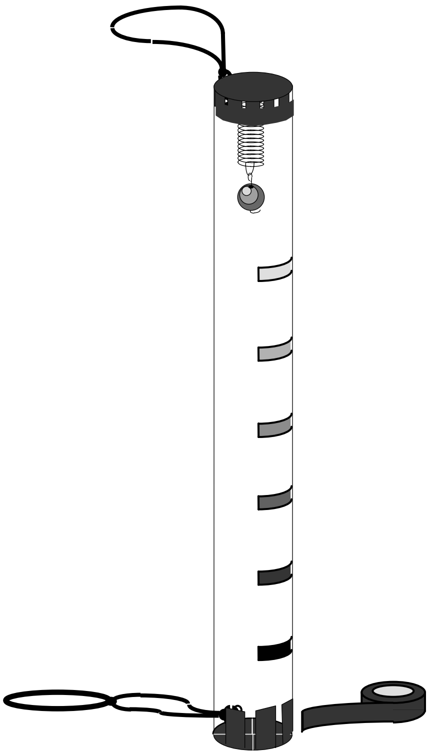
Twist the paper clip which suspends the spring as illustrated.

Step 9



Wind electrical tape around the paper clip. Ensure that the tape is wound tightly (do this by stretching the tape as you wind it onto the tube).

Step 10



Seal the top and bottom of the tube using electrical tape as shown. Wind electrical tape around the sealed ends as in Step 9 to secure the seals.

IMPORTANT: ENSURE SEALS ARE SECURED FIRMLY AND CANNOT PEEL OFF

Your vertical accelerometer is complete. Check the safety tests below, which will be conducted upon your arrival at Dreamworld

Safety Tests

The following tests will be conducted on each of your accelerometers upon arrival at Dreamworld, so it is important that you try them first. All three tests need to be passed in order for approval to use the accelerometer within Dreamworld. Accelerometers that meet the requirements receive an approval sticker to notify ride attendants. Only approved accelerometers will be allowed to ride.

Test 1 Wrist and Elbow Strap Inspection

- The wrist straps must secure the accelerometer firmly to the rider so that it cannot swing away if released

Test 2 Vigorous shaking

- The sinker must not detach itself from the spring during vigorous shaking of the accelerometer
- The sinker must not protrude though the sealed ends during or after vigorous shaking

Test 3 1.5 metre drop test onto carpeted floor

- The sinker must not detach itself from the spring when the accelerometer is dropped onto a carpeted floor from a height of 1.5 metres
- The sealed ends must remain intact after three drop tests