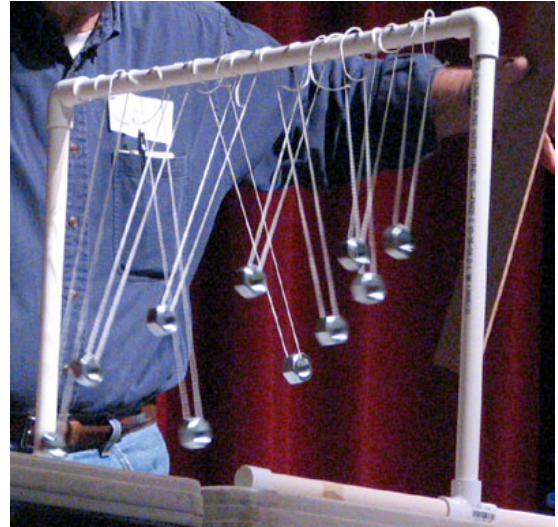
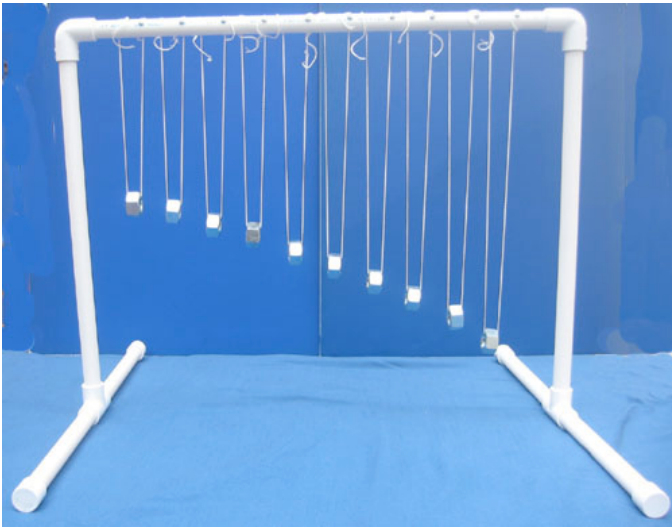


Pendulum Snake



NOTES

- this sheet is an addendum to the accompanying Pendulum Snake write-up created by Lori Lambertson -- Lori's write-up focuses primarily on construction – for more on the theory of the Pendulum Snake, see Paul Doherty's website: <http://www.exo.net/~pauld> -- go to the alphabetical listing of Scientific Explorations, and then to Pendulum Snake (or see the complete all-in-one URL reference on page 5 in Lori's handout)
- Lori's suggested use of a tapestry needle to thread the string is highly recommended – I would use the paper clip needle only if obtaining the tapestry needle is not feasible
- braided string is easier to work with than twisted string (some Mason's twine is braided)
- I used 3/4 in hex nuts rather than 1/2 in
- instead of using a knot on one end and a paper clip on the other end to secure the ends of a string, I drilled additional 1/8 in holes alternating on each side of the center line, as shown in the photo below, and then used sheet metal screws (#6, 1/2 in long, pan head, Phillips) to secure the strings

either of these two screws can be used to adjust the length of the same loop of string



Pendulum Snake

Build a snack version of the Exploratorium's Pendulum Snake exhibit!

Many people have helped develop this snack: Tien Hyunh-Dinh, Erik Thogerson, Thomas Humphrey, and Tory Brady.

Materials:

10 1/2" hex nuts

8 m string

1/2" Schedule 40 PVC pipe pieces:

1 58 cm long piece, drilled

2 45 cm long pieces

4 25 cm long pieces

2 elbow joints

2 T joints

4 end caps

10 paper clips

1 more paper clip OR a tapestry needle (which works *much* better than the paper clip "needle")

21" long piece of 1" x 4"

PVC cutters

Drill and 1/8" drill bit

masking tape

scissors

metric measuring tape

pencil

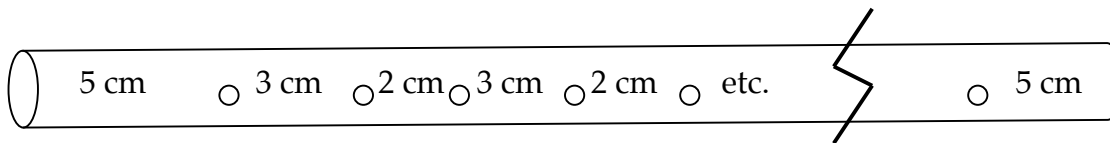
a method for calculating the desired lengths (or a list of lengths already calculated – the list is included in this write up)

To Assemble:

1) Cut the PVC pipe into the lengths specified above.

2) Mark the 58 cm long piece with a pencil as follows:

Make your first mark 5 cm from one end. Measure 3 cm from that mark, and make your second mark. The third mark is 2 cm from the second mark. The fourth mark is 3 cm from the previous mark. The fifth mark is 2 cm from the last mark. Keep marking 3 cm and 2 cm lengths, alternating until you are 5 cm from the end of the pipe. You should have 20 marks when you are finished.



3) These marks are the places to drill through the PVC pipe. Drill all the way through the pipe at each mark, making sure the holes are lined up. It is helpful to have some way to keep the pipe from rolling as you drill it.

If you don't have a tapestry needle, then do the following Steps 4 – 6. If you have a tapestry needle, thread it with the nylon twine, and go to Step 7.

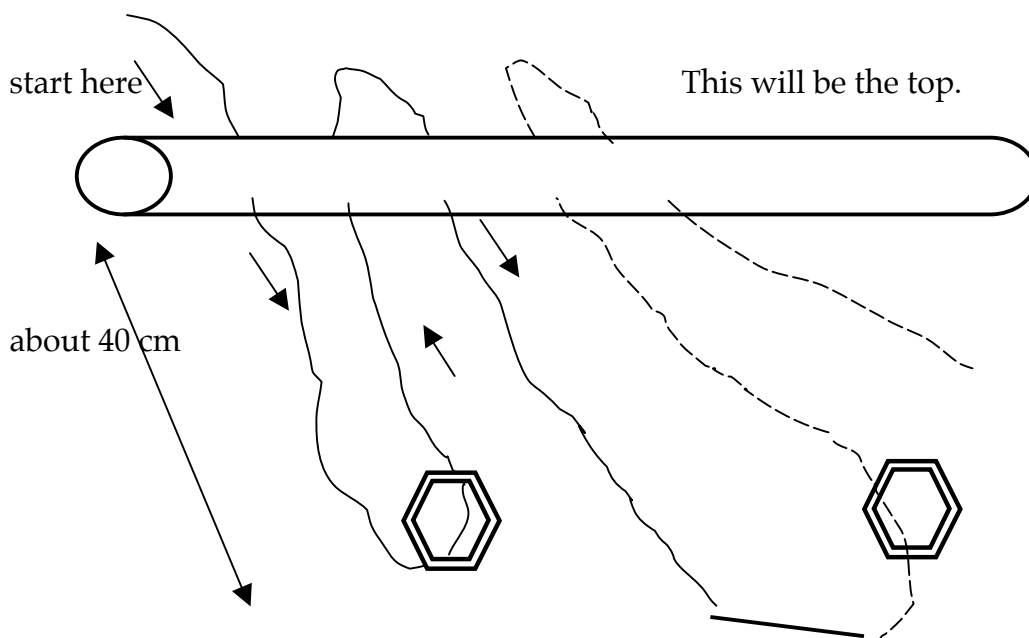
4) Straighten out a paper clip, making it as straight as possible.

5) Use a SMALL piece of masking tape to attach the straightened paper clip to the end of the string.

6) Trim away any excess tape, creating a smooth transition between the paper clip and the string. This paper clip will be your "needle" for threading the string through the holes.

7) Thread the string through the hole nearest one of the ends of the drilled pipe.

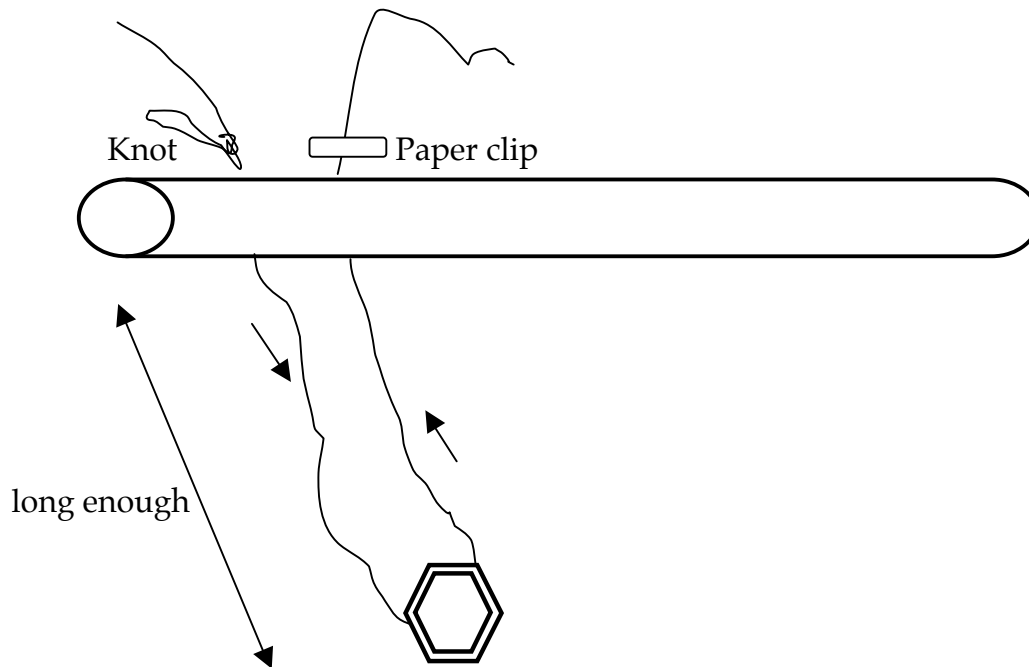
8) Thread a hex nut onto the string, and then thread it back through the next adjacent hole in the pipe. Then thread the string through the third hole. The dotted lines show how the second hex nut is added.



9) Try to thread all 10 hex nuts in this manner without cutting the string until you have completed all 10 loops. (If the string starts getting all twisted and knotted, just cut it, knot it, and go on with your threading.) You will need to keep pulling the string through the holes. This is easier if you have a partner, and if you keep your work flat on a table. The first loop on which you threaded a hex nut should be at least 40 cm long. Each successive loop will be a little shorter. Be sure to add a hex nut to each loop.

Alternatively, you can complete one 40 cm loop with a hex nut, thread the string back through the pipe (so that it is back on the top), and cut the string. Tie a double knot in one end of the string (above one hole) to keep the string from pulling back through. Clip a paper clip on the other end of the string (above the hole) to keep it from pulling back through. (see drawing on next page)

IMPORTANT NOTE: Each pendulum bob (hex nut) will hang from TWO strings that are 3 cm apart - one string is fixed in place with a knot, the other string is adjustable with a paper clip. As you thread the string through the pipe to create each loop, CHECK YOUR CALCULATED LENGTHS to make sure you are making the loops long enough! Make them all several cm longer than you need them.



How to calculate the correct LENGTHS:

The longest pendulum on this snack is 38.79 cm (measured to the center of mass of the hex nut) and will swing back and forth 24 times in 30 seconds. This is the same length as the shortest pendulum on the exhibit.

Length (L)	Number of Back and Forth Swings in 30 seconds (N)
38.79 cm	24

Subsequent lengths can be calculated by using the following formula:

$$L_{n+1} = L_n (N/N + 1)^2$$

For example,

$$L_{25} = L_{24} (24/25)^2$$

$$L_{25} = 35.75 \text{ cm}$$

Length (L)	Number of Back and Forth Swings in 30 seconds (N)
38.79 cm	24
35.75	25
33.05	26
30.65	27
28.50	28
26.56	29
24.82	30
23.25	31
21.82	32
20.52	33

10) When you are done threading all 10 hex nuts onto 10 loops, pull enough string through so that when you cut the string you will have several cm of slack at the top between each pendulum. You need enough string to tie a knot and have some left over for the paper clip adjustment.

11) Do not attempt to make each pendulum the correct length.....yet. For now, just put a knot at the top of one side of the pendulum and a paper clip on the other side of the same pendulum. Do this to all 10 pendulums.

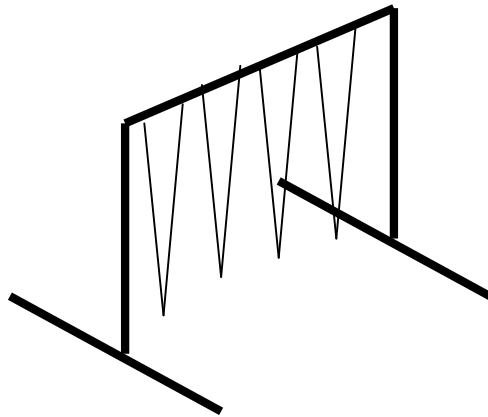
12) Assemble the frame: add an elbow joint to each end of the drilled pipe.

13) Put two 25 cm long pieces into the ends of the T joints that are opposite each other.

14) Put the 45 cm long pieces into the other ends of the T joints.

15) Have your partner hold the drilled pipe while you put the other ends of the 45 cm pieces into the elbows that you attached to the drilled pipe.

16) Add end caps to the 25 cm long pieces.



17) Your completed frame should look like the picture above (with more pendulums)

18) Use your calculated lengths, a partner, and a measuring tape to adjust each pendulum to the correct length by sliding the string up or down through the paper clip.

19) Add a knot to the end of each string to prevent fraying.

NOTE: Be sure to measure from the center of the two hanging strings to the center of mass of the bob. (Where is the center of mass of a hex nut? In the center of the hole!)

To Do and Notice (finally!)

1) Use your 1" x 4" board to pull all the bobs to the side simultaneously.

2) Release the bobs simultaneously.

3) Enjoy the show.

4) Not all bobs will be in "tune" at first. Adjust as necessary to get desired results.

Extensions:

Paul Doherty has some good ideas for investigations on his web site:

<http://www.exo.net/~pauld/activities/pendulums/pendulumsnake.html>