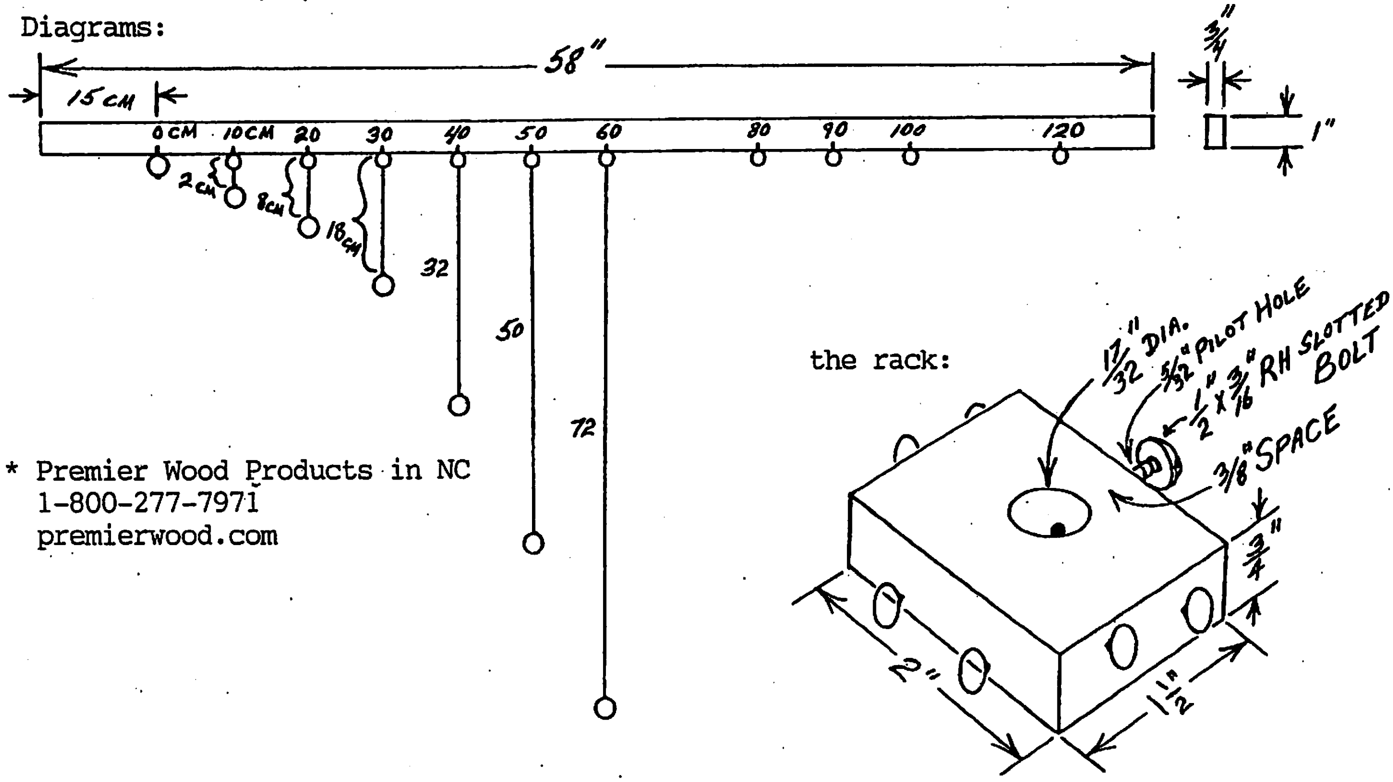
John B. Johnston, The Faraday Center, 103 Creamery Rd., Livingston Manor, NY 12758
(845) 439 - 4706

2-D Motion - a teaching model. The moment that gravity is included in a discussion of the motion of a projectile through the air, the explanation gets complicated for many beginning physics students. Now the students have to think vertically and horizontally at the same time, usually something they have not done before. An old, helpful method is the use of a teaching model made mostly out of wood or other materials that are handy. Today some people point to computer simulation to teach 2-D motion, but having a simple piece of apparatus that really interacts with gravity is more realistic and may be more effective. Its construction is simple and requires no special skills.

Materials: #1 or clear white pine, 16 screw eyes (No. 214), 7-3/4" solid wood balls*, coarse nylon thread (S-W?), 6 #3 paper clips, 1 #4 penny finishing nail, hammer, ½" x 3/16" RH slotted bolt, screwdriver, pencil, 17/32" drill bit, meter stick, awl, 1 #6 penny finishing nail, 5/32" drill bit, 1/16" drill bit for screw eyes and wood balls, (needle?)

Diagrams:



* Premier Wood Products in NC
1-800-277-7971
premierwood.com

Construction: Choose a pine stick or broom handle like the one in the diagram. Mark the stick in centimeters for the small holes to be drilled for the screw eyes. Set up a drill press to drill the 1/16" holes in the stick and seven, 3/4" dia. solid wood balls, and drill them. At point 0 cm, hammer a #4 penny finishing nail through a wood ball into the stick. Twist in the screw eyes at the points 10 cm to 120 cm as shown in the diagram. Screw eyes at points 70 and 110 are not neccessary. Paint the wood balls to show up better, if you wish, including the one at 0 cm.
Make up the six strands with nylon thread, wood balls, and #3 paper clips. Start by threading a ball; make a large knot on the end of the thread to hold the ball. Measure out a length of thread off of the spool as in the diagram, plus 8 cm extra; cut the thread. Bend outward one end of a paper clip to make a "hook"; tie the thread to the paper clip, matching the length as close as possible to that in the diagram. Make up all six strands and keep each separate so they don't get tangled. **

How to display? One suggestion is to set up two table-edge clamps with 1 m long support rods about 130 cm apart with right angle clamps near the top. Level the stick on the clamps. If the clamps won't hold the stick, add short rods to the clamps so they will. Now hang the strands on the screw eyes as in the diagram. Is the trajectory of the balls parabolic?

During the presentation, the strands are going to be removed from the stick. Where are you going to hang them without problems? One suggestion is to make a "rack", a wood block (pine) with six screw eyes that attaches to one of the poles. See diagram. Drill a 17/32" dia. hole for the pole and a 5/32" pilot hole for the "set screw" (a ½" x 3/16" RH slotted bolt or thumb screw). The set screw should self-thread in the soft pine. Remove the stick with strands and one clamp and place the rack high up on the "zero" (left) end pole. Tighten the set screw carefully (slightly); don't strip the soft wood threads. Replace the clamp and stick with strands. All is ready for presentation.

Presentation: These are suggestions only; present as you see fit.

(a) For horizontal projectile motion, assume that the wood ball is a 1776 musket ball fired from a gun. Assume that the initial powder charge gives the ball a muzzle velocity of 10 m/sec. Where is the ball one second later? Ans.: out horizontally 10 m and down 4.9m; on our stick, out 10 cm and down 2 cm (a slightly distorted scale). Where is the ball two seconds later? Out to 20 cm and down 8 cm (4X as far). After three seconds, out to 30 cm and down 18 cm (9X as far). And so on. At the six-second mark, the ball has reached 60 cm and down 72 cm. The trajectory is a nice parabolic curve. Where is its focal point (approx.)?
Now add enough powder so the ball leaves the gun's muzzle at 20 m/sec. Go through the progression again. After one second, the ball is out to the 20 cm mark but still down only 2 cm; remove the second, 8 cm strand from the 20 cm mark replacing it with the first, 2 cm strand. Temporarily place the second, 8 cm strand on the rack. After two seconds, the ball is out to the 40 cm mark but still down only 8 cm (4X as far). Remove the fourth, 32 cm strand, placing it on the rack; place the second, 8 cm strand at the 40 cm mark. After three seconds the ball is out to the 60 cm mark and still down 18 cm. Keep moving the strands accordingly. The 72 cm strand will now be at the 120 cm mark. Are the students catching on that more powder only pushes the ball out farther but can't stop its free-fall, that the trajectory will remain parabolic but "flatten" out? Where is its focal point now?
You can go through the progression again using 30 m/sec and/or 40 m/sec, if necessary. Finally, go through the progression using 60 m/sec and 120 m/sec. Do the students begin to see that the parabolic curve is beginning to resemble or "parallel" the earth's curvature? That if the muzzle velocity could be raised to about 19,000 mi/hr, the ball could orbit the earth? Sadly, a gun provides only one explosion for a fraction of a second. To reach 19,000 mi/hr requires continuous explosions for over 20 minutes; that's what a space rocket can do to put an object into orbit. And of course, the parabolic curve transforms into its very close relative, an ellipse; the parabola's focal point becomes one of the ellipse's two focal points. Neat!

(b) Now return the six strands going from the 20 cm to the 120 cm marks. Carefully remove the stick with strands from the horizontal display. Holding the stick at the zero (left) end, slowly raise the far (right) end to show a projectile's trajectory if fired at an angle above the horizontal. Note that the "free-fall" parabola is maintained. Raise the stick to a 45° angle; note that a maximum horizontal displacement and a symetrical parabolic curve (trajectory) are achieved with the gun's muzzle (0 cm mark). If the angle exceeds 45° the horizontal displacement decreases while the vertical displacement increases. (You can learn all of this while playing with a garden hose.) Now lower the stick to an angle below the horizontal. Again, the "free-fall" parabolic curve (trajectory) is maintained. Gravity is consistent. Besides changing the angles of the stick, you can imagine changing muzzle velocities of the projectile, as well.

(c) This study with this teaching model is a perfect introduction to explaining the concepts involved in the well-known demonstration, "The monkey and the hunter". See it listed on the website.

(d) This teaching model will also enhance the discussion of an airplane dropping a free-fall package (bomb?) on a target, that is, the importance of altitude (time in the air) and horizontal velocity (range).

** The second, 2 cm strand is too short for a paper clip and thread. Instead, bend a short piece of #18 soft copper wire into this shape with the ball on it.