GARAGE PHYSICS

by eisco

Projectile Motion Slingshot Kit

GP00014

Guide for Educators

Projectile motion can be done in a small way. Or it can be done in a BIG way. This kit allows students to explore projectile motion writ-large with a rubber-band slingshot! The set is simple to prepare no additional tools are required. Set-up takes only 10 minutes! Students can use the included ping pong ball, or other projectiles of their own design. Launches are highly repeatable giving consistent experimental results. The included stand allows exploration of launch angles from 0° to 45° in increments of 5°. The kit can be used to study projectile motion as well Hooke's law.

NGSS Standards

Motion and Stability: Forces and Interactions
MS-PS2-2

Contents of Kit

1 Slingshot frame, 2 slingshot frame supports, 1 release mechanism support, 2 angled stands, 1 angled stand support, 4 #32 rubber bands, 1 ping pong ball, 1 leather pouch, 1 cotter pin, 1 cotter pin string.

Pedagogical Guide

Assembly

1) Insert the 2 slingshot frame supports into the slingshot frame. The bottom of the supports should be flush with the bottom of the frame when seated properly. You may need to use a hammer to tap them into place.

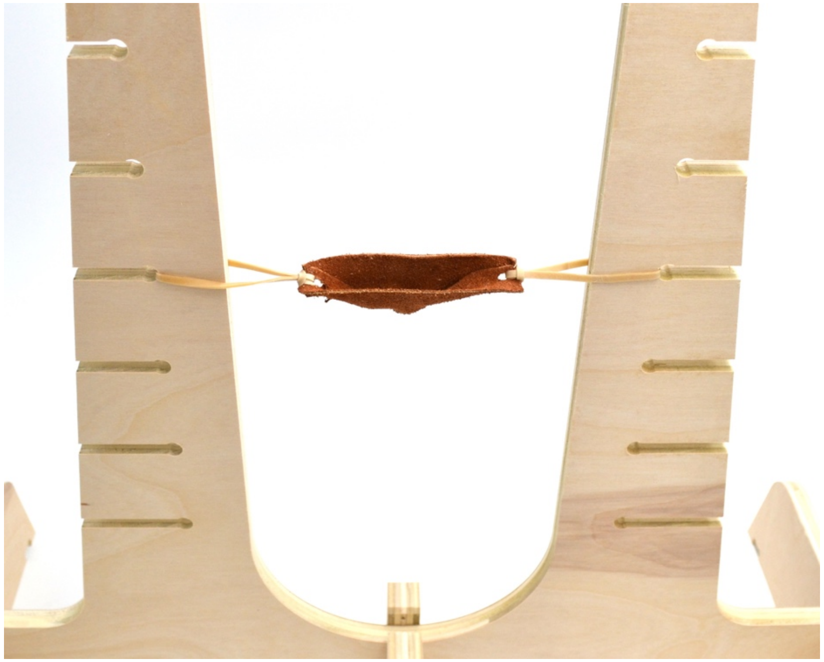
2) Attach the angled stand support to the two angled stands. The bottom of the supports should be flush with the bottom of the stands when seated properly. The stand angles are from 5° to 45° in 5° increments.

3) Tie the slingshot pouch. *This is a critical part of the assembly instructions and must be followed closely for the slingshot to give repeatable results.*

   a) Identify the smoothest side of the leather pouch. This is the top. Insert one of the rubber bands down through the holes sequentially so the leather flaps overlap. The pouch will not release the ping pong ball as effectively if the rubber band is inserted in any other way.

b) Pull the loop from the back around the loop in front.
c) Carefully cinch tight.
d) Repeat on the other side.

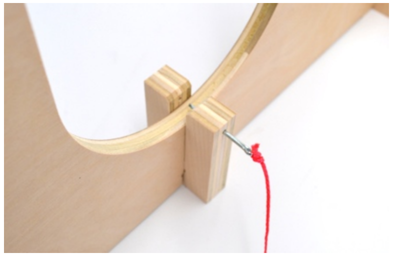
4) Pull the rubber band loops over the arms of the slingshot to the desired height, one on each side. The holes in the slingshot arms are separated by 5 cm.

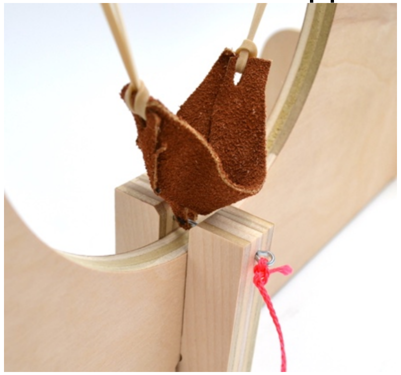


5) Tie the included string onto the cotter pin loop.

Loading and Launching

6) Pull the pouch down toward the bottom of the slingshot. Insert the cotter pin through the hole at the bottom of the slingshot and loop the thin strap at the bottom of the pouch over the cotter pin. Continue pushing on the cotter pin to insert it into the open hole in the release mechanism support.



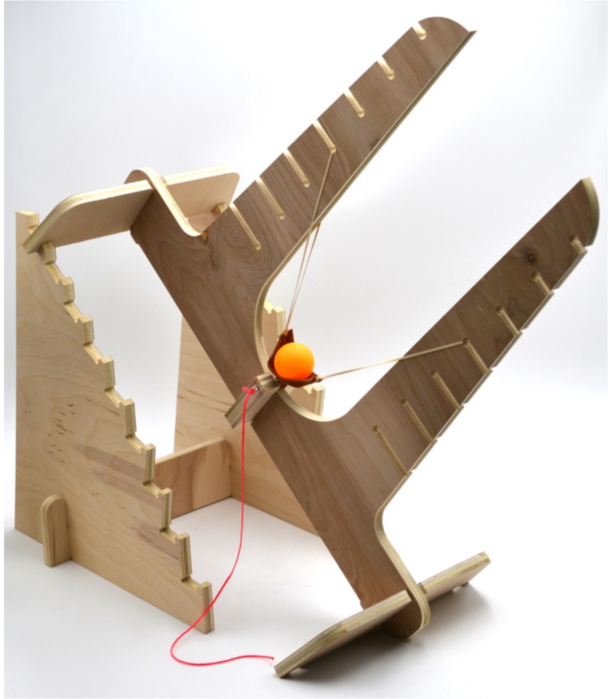


7) Insert the ping pong ball into the pouch. You are now ready to launch.

WARNING!!!
If the rubber bands are in the top holes of the slingshot, use a pencil or pen to push down and secure the pouch. This will keep your hands from getting hurt if the rubber band breaks!
WARNING!!!

8) While one student aims the slingshot and holds it steady, another student pulls the cotter pin out, launching the ping pong ball. A third student can be downrange to record the landing position of the ping pong ball.

9) You can use the angled base to launch the ping pong ball at an angle. The angles are in 5° increments from the bottom (5°) to the top (45°).



Understanding Projectile Motion

10) Use the slow-motion capture feature on a cell phone camera to record the launch from the side. What do you observe?

11) Use the stop-watch or video-recorder feature on a cell phone to measure the flight-time (the time that the ping-pong ball is in the air). Does the flight time change when you change the angle of the slingshot?

11) Launch the ping pong ball vertically from different sets of holes in the slingshot arm. Record the flight-times in the chart below. How does this affect the flight-time?

12) Divide the flight time in half and then multiply by $9.8\ m/s^2$ (or simply multiply the flight-time by $4.9\ m/s^2$). This gives a rough estimate of the initial velocity. Why? [Gravity reduces the initial velocity by $9.8\ m/s$ each second until the ping-pong ball reaches the apex and has zero velocity. Then gravity increases the velocity in the downward direction by $9.8\ m/s$ each second until the ping-pong ball hits the ground. Thus, if the take the total time it takes to get to the apex (flight-time/2) and multiply that by $9.8\ m/s^2$, we get the initial velocity.] Record these values in the chart.

13) Calculate the initial kinetic energy using the mass of your projectile,

$$K = \frac{1}{2}mv^2.$$

Ping-pong balls typically have a mass of $2.8\ g$. Record these values in the chart.

14) When the ping-pong ball is launched, both it and the pouch are traveling at the same speed. The pouch weighs about $3.5\ g$. Calculate the initial kinetic energy of the pouch and record these values in the chart. (You can just multiply each ping-pong kinetic energy by $3.5/2.8 = 1.25$).

15) Add the pouch and ping-pong ball kinetic energies to get the total initial kinetic energy. This must be equal to the total initial potential energy stored in the rubber band. Plot the total potential energy versus the displacement. What shape does the curve seem to have? [Quadratic].

Can you come up with a quadratic equation which follows the curve you plotted?

16) The coefficient in front of the y^2 term can be used to find the spring coefficient of the rubber bands. First, divide the coefficient by 2, and then by 2 again. The result is the spring coefficient of a single rubber band. Compare to the experimentally measured average spring constant of $88\ N/m$ of the #32 rubber band. Why might your result be slightly different?

Hole #	Displacement, y.	Flight-time, t	Initial Velocity, v	Initial kinetic energy (ping-pong ball),K_{pong}	Initial kinetic energy (pouch), K_{pouch}	Total initial kinetic energy, $K_{pong} + K_{pouch}$ = Slingshot total potential energy
1						
2						
3						
4						
5						
6						
7						

Follow-up Questions and Activities

Use trigonometric functions to predict the range.

In the previous section, we deduced the initial velocity for each possible displacement. If we tip the slingshot on the angled stand the initial velocity will have both a horizontal and vertical component.

The vertical component of the initial velocity determines the flight-time of the ping-pong ball. Why? [Gravity reduces the vertical component of the velocity until it reaches the apex where the velocity is zero. Then it increases the velocity in the downward direction until it lands. Since gravity reduces the velocity by $9.8\, m/s$ each second, the total flight-time is twice the number of times $9.8\, m/s$ can be divided into the initial velocity times two (once for the trip up, and once for the trip down).]

The horizontal component of the initial velocity and the flight-time determine the range (the distance the projectile travels in the horizontal direction). Why? [The projectile will move in the horizontal direction as long as it is in the air. Neglecting air-resistance, the velocity won’t change in that direction. So the total distance is just the horizontal component of the initial velocity times the flight-time.]

Trigonometric functions can be used to determine the horizontal and vertical components of the initial velocity.

Degrees from vertical, θ	Vertical multiplier, $\cos\ \theta$	Horizontal multiplier, $\sin\ \theta$
0	1.000	0.000
5	0.996	0.087
10	0.985	0.174
15	0.966	0.259
20	0.940	0.342
25	0.906	0.423
30	0.866	0.500
35	0.819	0.574
40	0.766	0.643
45	0.707	0.707

Use the above chart and previously recorded initial velocities to predict the range for a few displacements and angles. Once you've recorded your prediction, launch the ping-pong ball with the same hole and angle settings and measure the range. Record your settings, prediction and calculation in the chart below. Averaging the result of multiple launches will help smooth out experimental variations.

Compare your prediction to the measured result. What might account for the difference? [The main discrepancy is air-resistance of the ping-pong ball. Sometimes the ping pong ball acquires a spin as it leaves the pouch. This can also influence the trajectory.]

Hole #	Initial Velocity, v	Degrees from vertical, θ	Vertical component of initial velocity, v_y	Horizontal component of initial velocity, v_x	Predicted flight-time, t	Predicted range, r_{pred}	Measured range, r_{meas}