GARAGE PHYSICS

by eisco

Ballista Kit

GP00016

Guide for Educators

Learn physics through play! This kit is built from simple components – wood, leather, and string – but has an amazing result. Once built, students can launch ping pong balls more than 30 ft and explore 4 different launch angles. Projectiles can be launched in a repeatably making for a safe and fun way to explore parabolic trajectories. Launch your way into a tactile exploration of fundamental concepts of physics!

Educational topics covered in the kit include torsion springs, forces, acceleration, and parabolic trajectories.

Contents of Kit

Ballista sides (2), base supports (2), torsion frame top and base, torsion frame sides (2), leather pouch, ping pong ball, 2“ dowels (4), 7“ dowels (2), 19“ string (2), 25“ string (2), 7“ string

Background

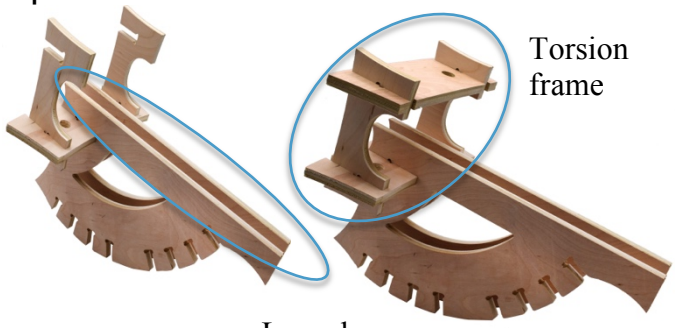
Ballistas were a particularly efficient siege warfare machine. Though the weight and range of their projectiles was typically smaller than the trebuchet, they required no counterweight and could be reloaded quickly by a single person. This meant they could be repositioned and fired quickly enough to be effective against moving targets such as armored troops. Large ballistas were able to achieve distances around 1 km.

This ballista uses torsion spring bundles and lever arms. The torsion spring bundles are made of twisted mason twine and exert a rotational force, or torque, on the lever arms. The two lever arms pull on the pouch, accelerating the ping pong ball away from the ballista. Once the ping pong ball leaves the ballista it travels along a parabolic trajectory (ignoring air resistance).

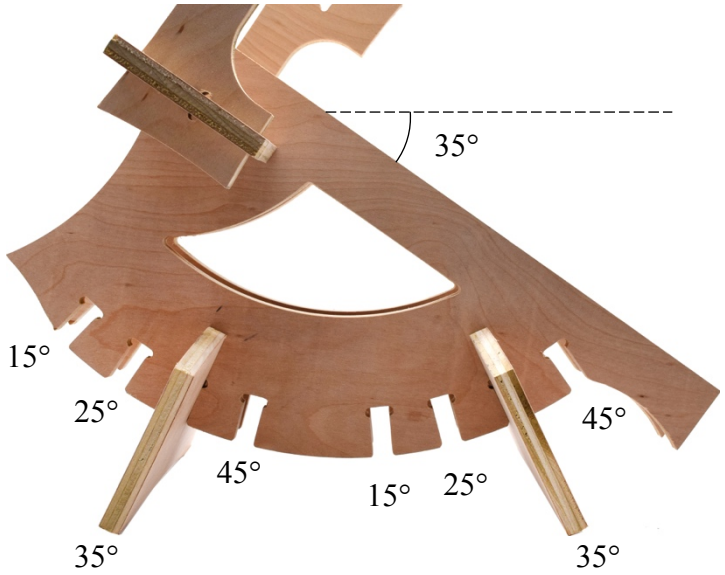
Assembly

1) Insert the torsion frame bottom into the two side pieces.

2) Insert the torsion frame side pieces into the torsion frame bottom. Then insert the torsion frame top to complete the torsion frame.



3) Insert the base supports into slots on the underside of the ballista. The slots are paired to give specific launch angles, from 15° to 45° in 10° increments.



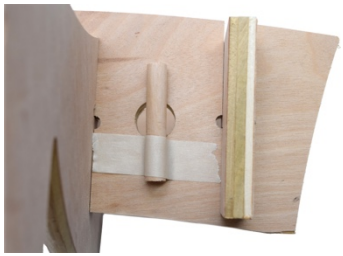
4) Assemble the torsion spring bundle.

Overview: Wrap the 25” string twice around the small dowels with one above and one below the torsion frame and tie a square knot.

Step-by-step:

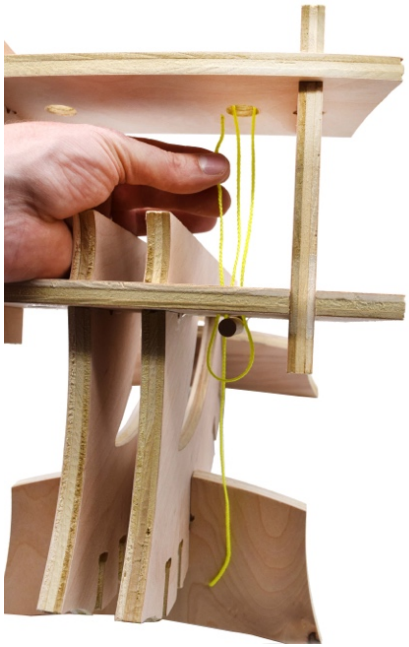
a) Though not required, it helps to tape the small dowels across the holes on the top and bottom of the torsion frame. Either Scotch or masking tape works fine.

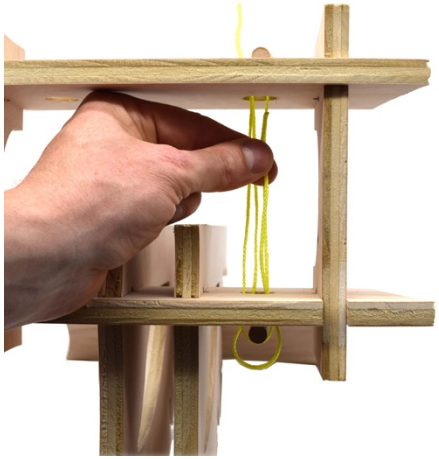
Top view

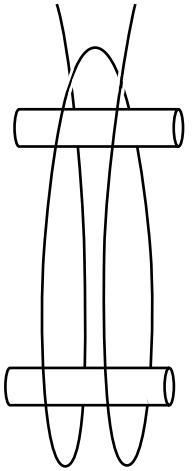


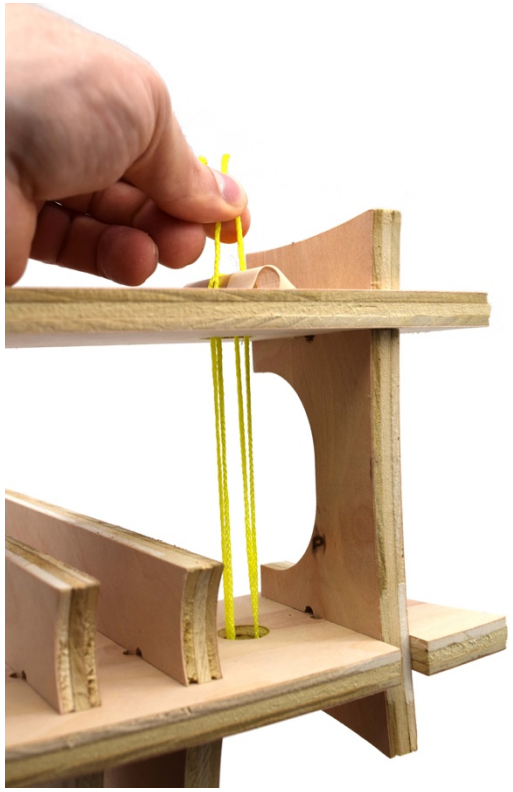
Bottom view

a) Thread the 25” string down through the sides of both holes, and then around the bottom dowel and back up to the top.

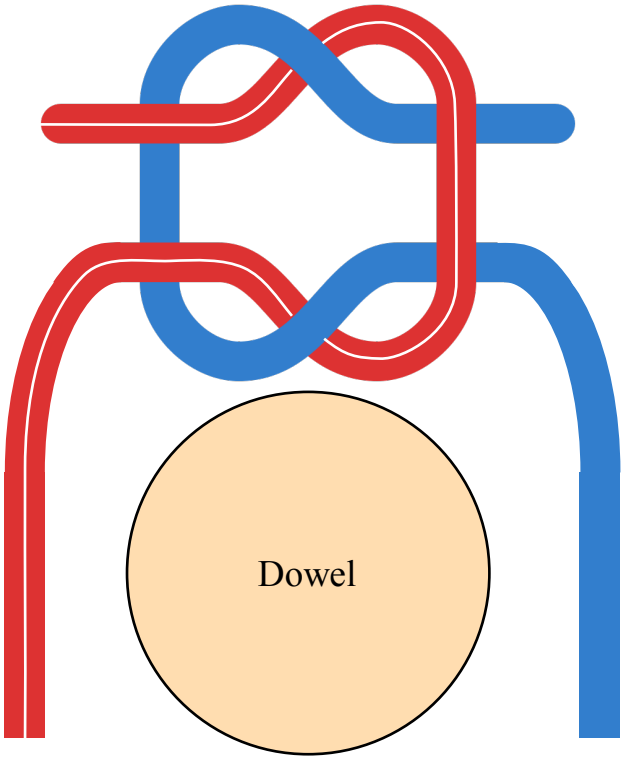








b) Tighten the string, and then while keeping it taut, tie a square knot by tying a left-overhand knot and a right-overhand knot in sequence. You can add an additional left-overhand knot to secure the square knot further (not shown here).



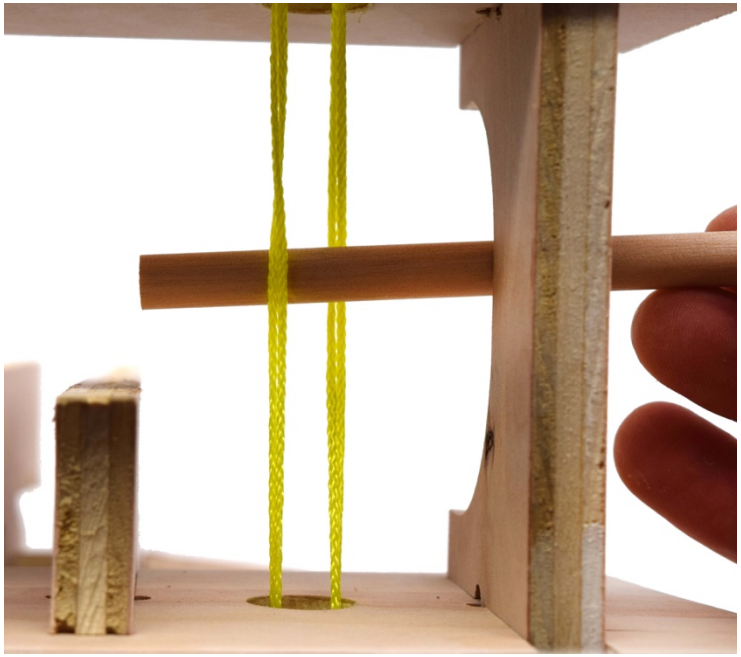
c) Repeat the process for the other side.

5) Add the lever arm and tighten the torsion spring bundle.

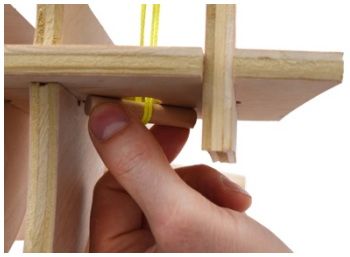
Overview: Insert the lever arm between the pairs of string so that the end is flush with the ballista side. Remove the tape on the top dowel and twist it a full turn clockwise for the left lever arm (counter-clockwise for the right lever arm). Flip the ballista over and do the same for the lower dowel, but twist in the opposite direction. Continue to twist the top and bottom dowels with the same number of turns. Do the same for the opposite side.

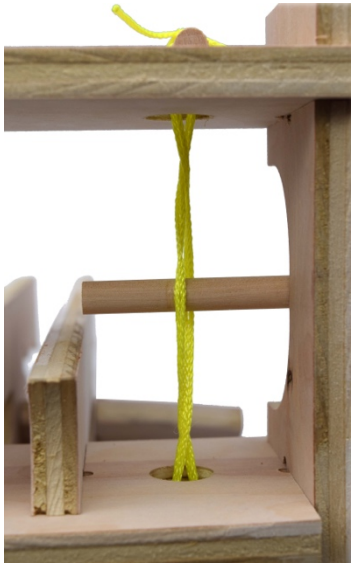
Step-by-step:

a) Insert the lever arm between the pairs of strings so the end is flush with the ballista launch guide.



b) While continuing to hold the lever arm, remove the tape from the top dowel and turn the top dowel one full turn – clockwise for the left lever arm, and counter-clockwise for the right lever arm. Flip the ballista over and do the same for the lower dowel but in the opposite direction.

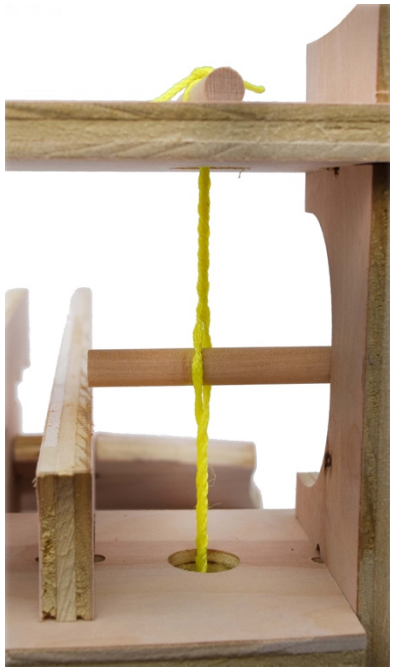




c) Repeat step b), alternately tightening top and bottom dowel in equal amounts, *keeping track of the total number of turns*, until the lever arm quickly springs back into place against the torsion frame when pulled back and released. Tightening both the top and bottom dowels equally is very important, otherwise the lever arm will not be vertically centered in the torsion frame.

d) As you tighten the dowels, periodically check that the end of the lever arm is roughly even

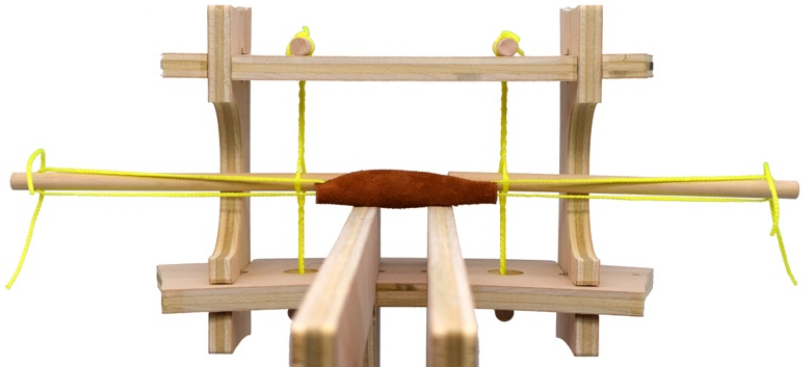
with the edge of the launch guide. Try to keep the twisted line roughly centered in the hole of the torsion frame.



e) Repeat steps a)-d) on the other lever arm, tightening the dowels the same number of turns as on the previous lever arm. It is important that the torsion spring bundles are equally tight, otherwise the ballista will not be balanced, and may not shoot straight.

6) Tie the launch pouch to the ballista.

Overview: Rotate the lever arms so the slot faces forward. Thread the 19” string through two holes of the pouch and in opposite directions through the lever arm slot. Tie a square knot behind lever arm slot. Repeat on the other side so that the pouch is centered in the torsion frame.



Step-by-step:

a) Thread each 19” string through two neighboring holes on the narrow sides of the pouch.

b) Though not required, it helps to temporarily tape the pouch to the launch guide to hold it in place.

c) On each lever arm, run the ends of the string in opposite directions through the hole in the lever arm. An easy way to do this is to thread one sting through the hole. Then tape the remaining string to the first with some of the first string extending beyond the tape. Pull the taped section through the hole. Then remove the tape without pulling the first string all the way through the hole.

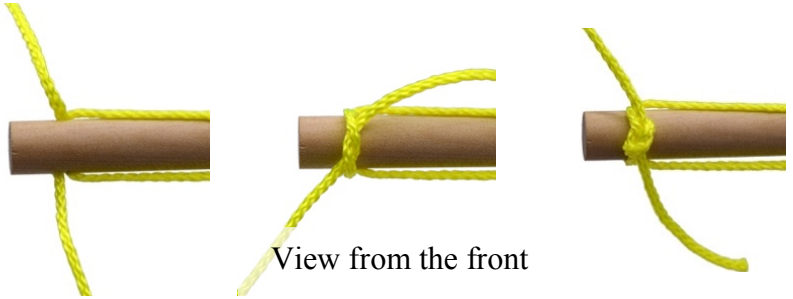
Leave an extra inch or more extended below the tape.

Wrap tape tightly around both strings.

Pull the tape through but not the extra string.

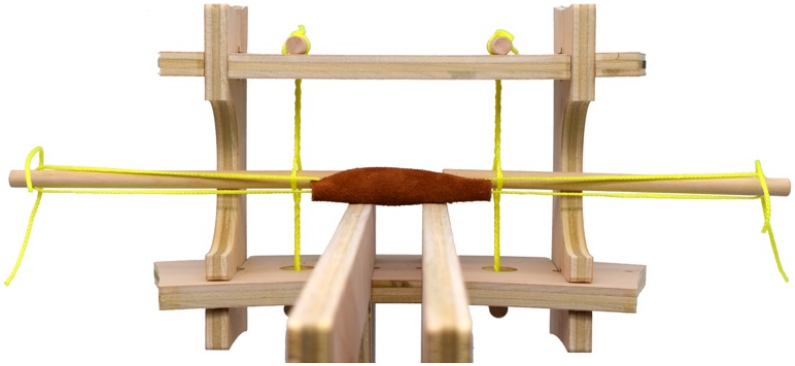
Carefully remove the tape without pulling the extra string through.

d) Tie a square knot on the front of the dowel.

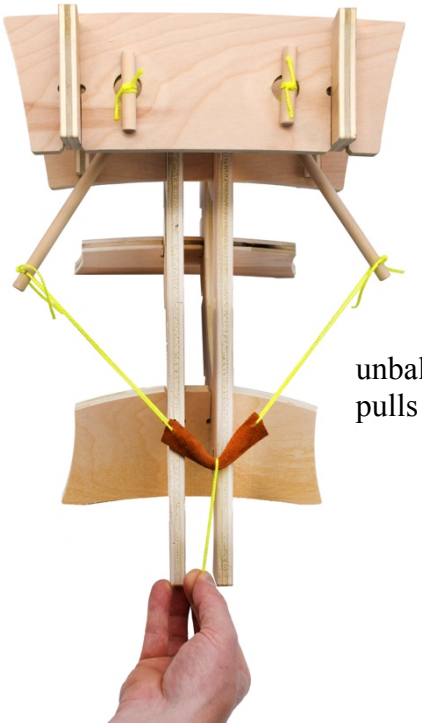


View from the front

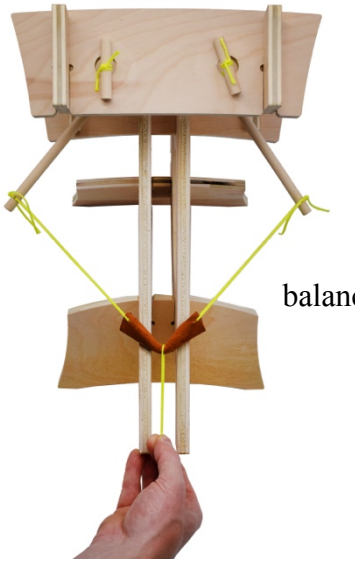
e) Repeat on the other side, and then remove the tape on the pouch.



7) Balance the ballista using the remaining piece of string. Loop the string around the pouch and pull the pouch about half-way back along the launch guide. Look to see if the ballista pulls the pouch to the right or the left (see pictures on page 10). If it pulls to one side, then tighten the torsion spring bundle on the other side (be sure to tighten the top and bottom dowels equally, of course).



unbalanced –
pulls to right

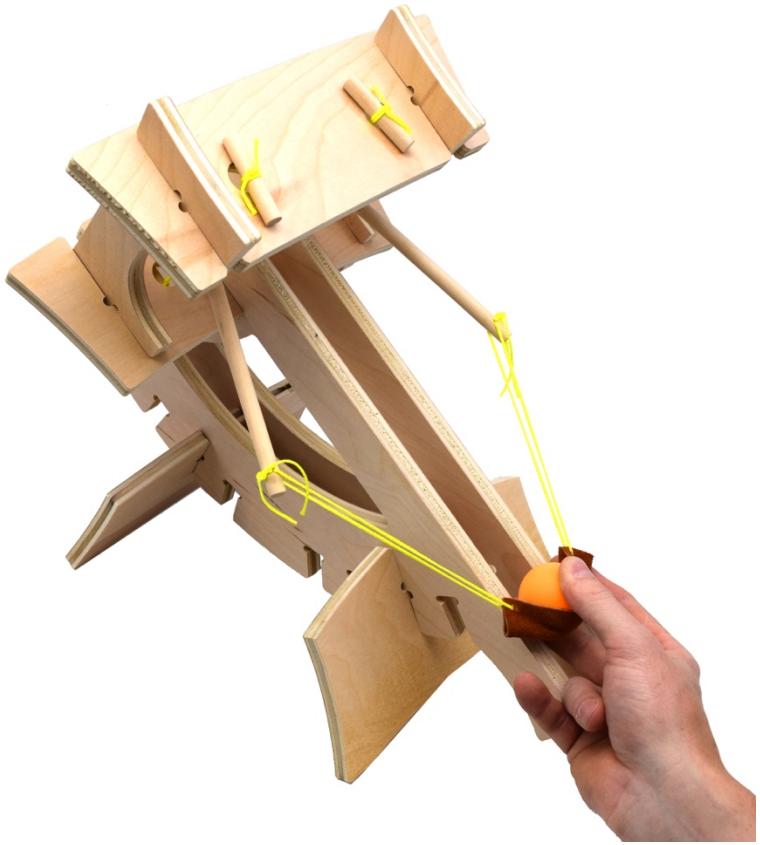


balanced

Launching

8) To launch the ping pong ball, load the ping pong ball in the pouch and pull back the loaded pouch. Release to launch.

Launch ranges exceeding 30' can be achieved if the torsion spring bundles are sufficiently tight and the launch angle isn't too flat or too steep.



Exploration

By changing the positions of base supports and the pull-back distance of the ping pong ball, various trajectories can be explored.

1) Set up a target and see how far away you can get before the target is out of range. Which launch angles give the largest range?

2) Set your target up high, such as in a tree or on a play structure. Which settings give the highest trajectory? Can you launch the ping pong ball over a goal post, for example?

3) Make your target more and more sturdy. For example, try stacking paper cups or soda cans filled with water. Which base support settings and pull-back distance give the hardest impact?

4) Place your target behind a barrier of some kind. How can you adjust the launch settings to hit the target?

Explain your observations during the previous four scenarios.

The ballista trajectory can be changed by adjusting the pull-back distance and the launch angle. Which

do you think is the most important factor in determining the largest range? Why?

You can calibrate your ballista by taping a ruler (not included) to the launch guide (or simply making marks every ½"). Then fire at targets of known distances until you have determined the settings which allow you consistently hit or nearly hit the targets. Record the settings for each target distance. Then, when you need to hit a target of unknown distance, you'll know which settings to try, based on your visual estimate of the distance to the target.

For a projectile launched with constant speed at varying launch angles, the largest range is achieved at a launch angle of 45°. Is the largest range for this catapult achieved at a 45° launch angle? Why or why not? Can you explain why 45° is optimal for a projectile having a constant launch speed traveling in a parabolic trajectory?

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