The Physics of Baseball and Hit Charts

https://www.sciencebuddies.org/science-fair-projects/project-ideas/Sports_p060/sports-science/physics-of-baseball-hit-charts (http://www.sciencebuddies.org/science-fair-projects/project-ideas/Sports_p060/sports-science/physics-of-baseball-hit-charts)

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Experimental Procedure

Set Up Your Experiment

1. In this section, you will set up your experiment as shown in Figure 5, below. Read the following steps for detailed directions.

Figure 5. In the setup for this experiment, a rubber-band-powered catapult is mounted sideways (shown here using a C-clamp). It swings a wooden dowel like a baseball bat to hit a ping pong ball resting on a golf tee. Imagine the area where you set up the tee as "home plate" on a toy-sized baseball field.

2. Watch this video to learn how to use your catapult. Note that in this project you will mount the catapult sideways.

Video instructions for using your ping pong catapult.
https://www.youtube.com/watch?v=pIEjwMhnAGo (https://www.youtube.com/watch?v=pIEjwMhnAGo)

3. Assemble your catapult.

a. Get the catapult, metal pin, and a single rubber band from your catapult kit, as shown in Figure 6, below (top left).
b. Push the pin through the hole in the base of the catapult (the black part) to lock the circular metal disc in place, so the 45 on the disc is showing just below the black bar (see Figure 6, top right). Notice that the metal disc has multiple holes, so you have to push the pin through the right hole to line up the 45 just below the black bar.
c. There is a large hole at the top of the aluminum disc. Push a rubber band through this hole and hook each end of the rubber band around the pin that sticks through the catapult's launch arm (see Figure 6, bottom left).
d. When you have finished, the assembled catapult should look like the bottom right image in Figure 6.

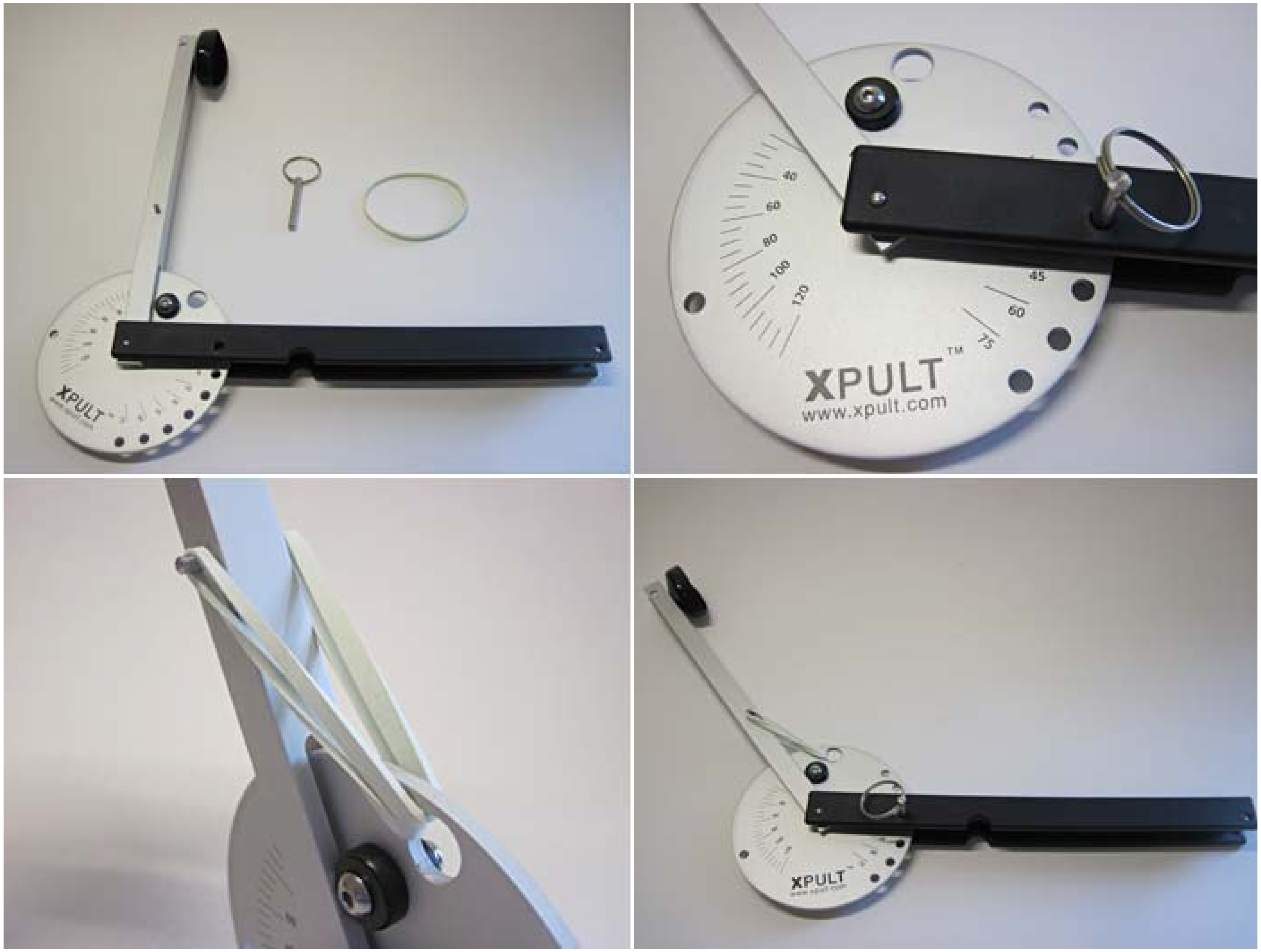

Figure 6. The catapult, rubber band, and pin (top left). Use the pin to lock the metal disc in place relative to the base of the catapult (top right), lining it up with the 45. Loop a rubber band through the large hole in the metal disc, and hook each end of the rubber band to the pin sticking through the launch arm (bottom left). The assembled catapult (bottom right).

4. Attach the "bat" to your catapult.
    a. Use duct tape to attach your wooden dowel to the back of the catapult arm, as shown in Figure 7, below.

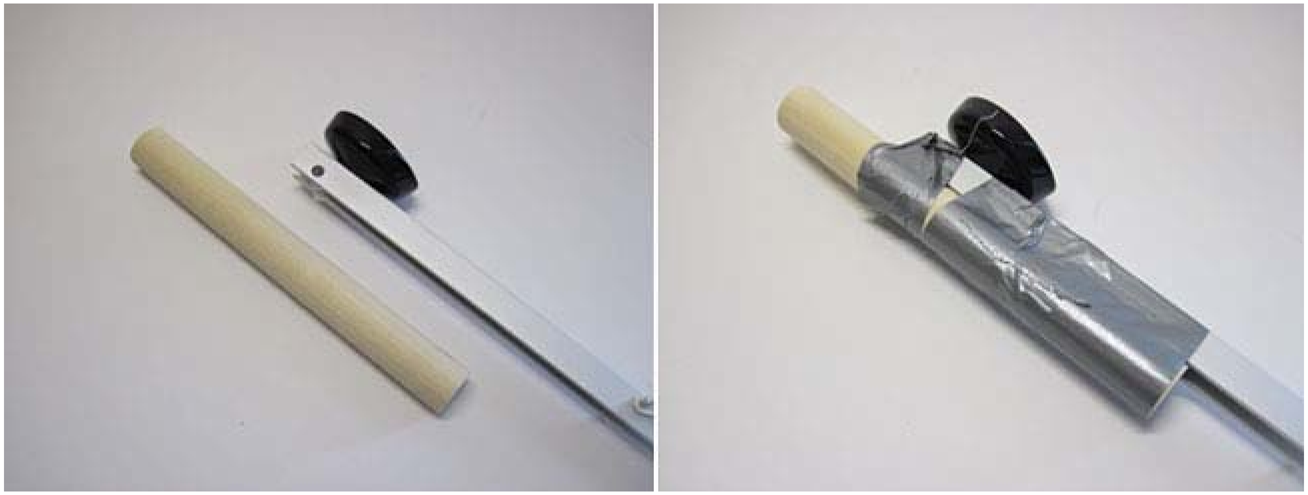

Figure 7. Use duct tape to attach the wooden dowel to the catapult arm.

5. Build your tee (Figure 8, below).
    a. From the sheet of corrugated cardboard, cut out a rectangle roughly 5 centimeters (cm) wide and 20 cm long.
    b. Fold the cardboard rectangle over on itself three times in roughly equal parts, to make a stack four layers thick.
    c. Use duct tape to hold the cardboard stack flat.
    d. Puncture the top three layers of cardboard with the golf tee.
    e. Superglue the golf tee in place.
    f. *Important*: Depending on where you set up your experiment, you might need to adjust the height of your tee. You can do this by placing it on a stack of books or small cardboard boxes if you need to.

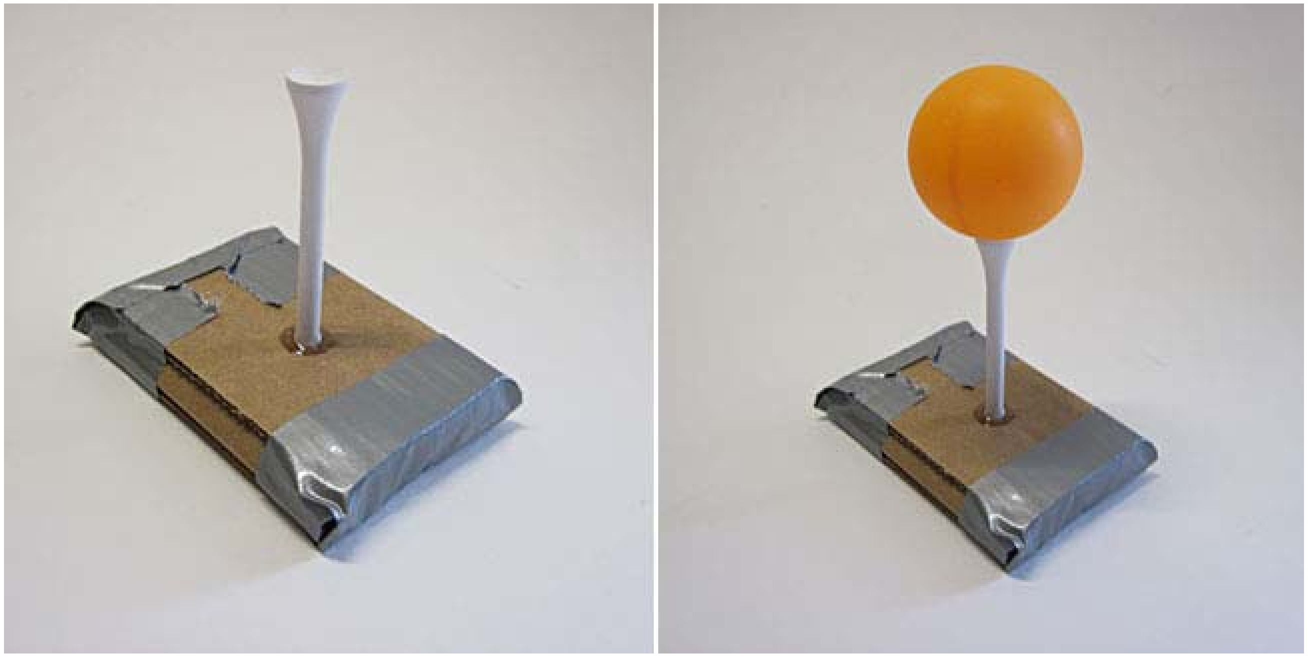

Figure 8. Cardboard, duct tape, and a golf tee make a simple tee to hold the ping pong ball. Use superglue to hold the base of the tee in place.

6. Create a cardboard ruler.
    a. You will use this ruler to measure the location of the tee as you move it forward and back, to simulate an early swing or a late swing.
    b. From the remaining cardboard, cut a rectangle about 20 x 8 cm.
    c. Use a metric ruler to make marks at 1 cm increments on the strip of cardboard, as shown in Figure 9, below.
    d. Label the marks with 0 in the middle, positive numbers on one side, and negative numbers on the other side, as shown in Figure 9.
        i. *Note*: whether you make your number line go negative to positive from left to right, or right to left, will depend on the orientation of your setup. Using the orientation shown in Figure 5, it was easier to read the number line with negative numbers on the right and positive on the left.

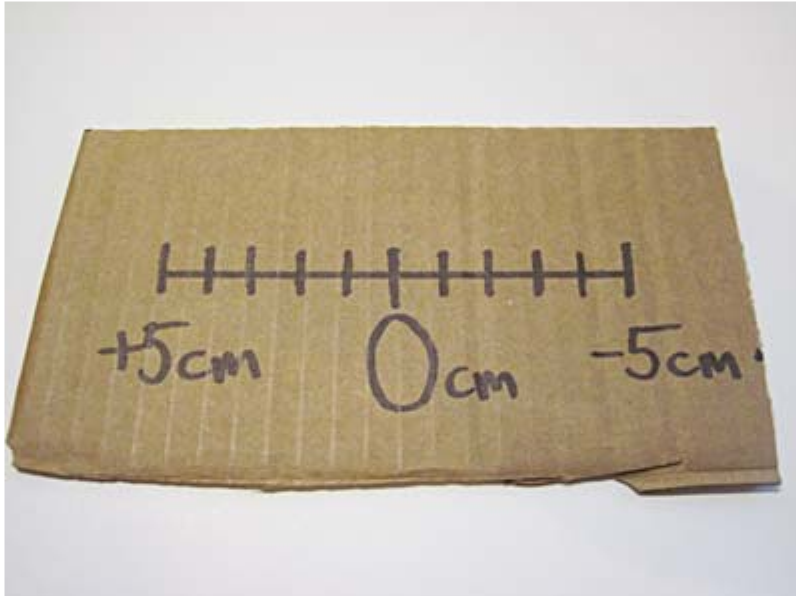

Figure 9. Cardboard ruler you will use to set the position of your tee (refer back to Figure 3 in the Introduction). The rule should have marks in 1 cm increments ranging from -5 to +5 (whether you go left to right or right to left depends on the orientation of your catapult when clamped to furniture, and the direction you will be hitting).

7. Clamp your catapult sideways to a sturdy object like the leg of a table or a fence post, as shown in Figure 10, below.
    a. Make sure you have a large, open area to work with. You should have at *least* 6 meters (m) of open space in front of the catapult, preferably more, especially if you are working on carpet, and 3 m on either side.
    b. A C-clamp will work better than the spring clamp that came with your catapult kit. You can buy a C-clamp with a wider opening, which enables you to clamp the catapult to thicker objects like fence posts. You can also tighten a C-clamp very well, so the catapult does not wobble between hits.
    c. If you do not want to scratch the furniture, use a paper towel or a dish towel as padding between the clamp and the furniture.
    d. Clamp your catapult to the object so that the height of the bat will roughly line up with the height of the ball when it is sitting in the tee. You will make exact adjustments to the position later.

Figure 10. Catapult clamped to the leg of a table using a C-clamp.

8. Align your catapult and tee.
    a. Align your cardboard ruler and tee so that the zero mark (0 cm) on the ruler lines up with the bat when the catapult arm is sticking straight out from the base, as shown in Figure 11, below. The ruler will be perpendicular to the bat arm. Make sure the positive side of the ruler is facing outward, in the direction the ball will be hit.
    b. Secure the ruler to the ground so it does not move. It is important that the ruler stays in the same place throughout the entire experiment and does not slide around.
        i. If you are working outside, you may need to come up with a creative way to hold the ruler in place, like using something heavy to weigh it down while not obscuring the centimeter marks or interfering with the dowel hitting the ball.
        ii. If you are working inside, you may be able to use duct tape to secure the ruler to the floor surface. Check with an adult before you do this, to make sure the tape will not damage the floor.
    c. If necessary, adjust the vertical position of your catapult so the bat lines up with the equator of the ball, as shown in Figure 11. You will need to loosen and then retighten the C-clamp to do this.
        i. You can also adjust the height of your tee by putting a book or more cardboard under it. The bat should touch the ball directly in the center, as shown in Figure 11, below.

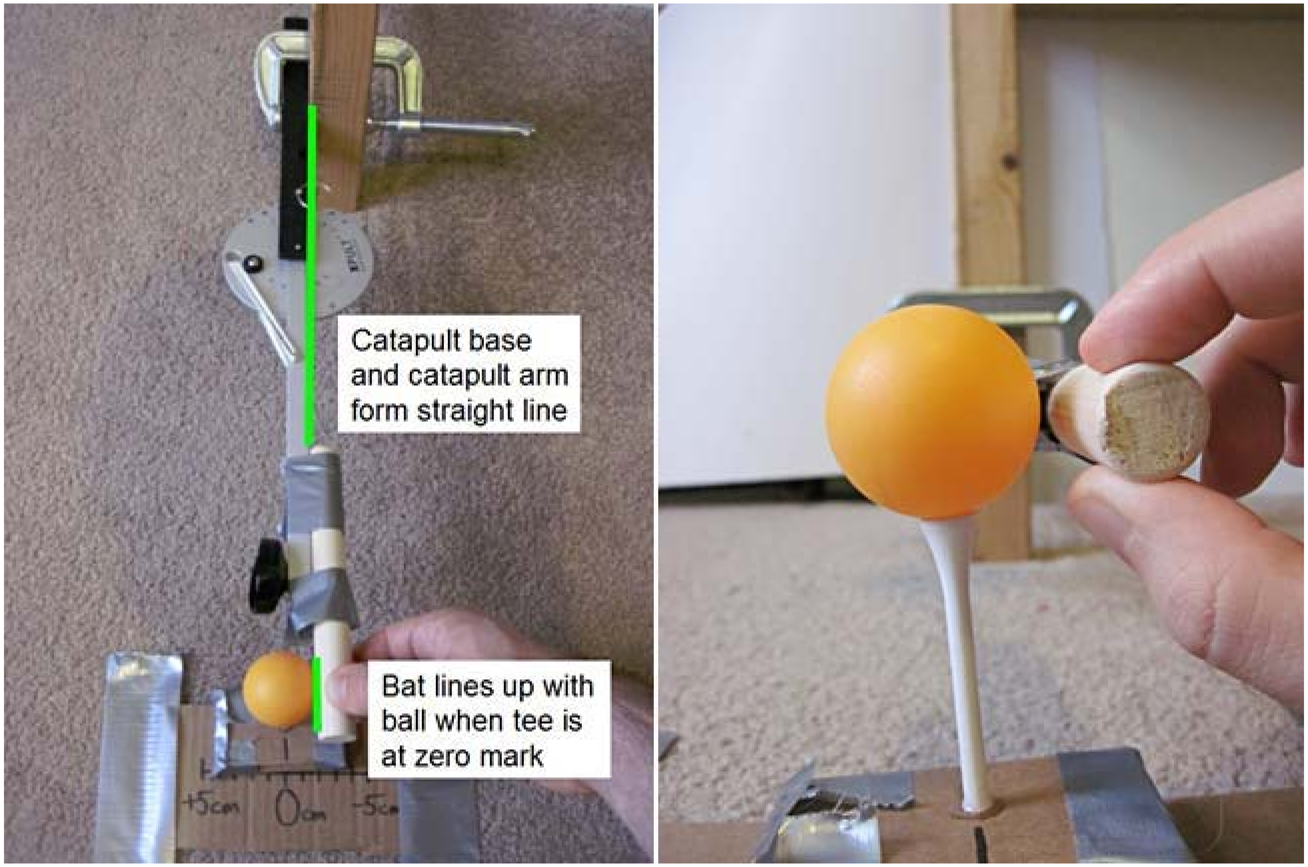

Figure 11. Line up the catapult and tee so the bat will hit the ball correctly. Left image: Place the ruler such that the zero mark lines up with the bat when it is sticking straight out from the catapult base (the black part). Right image: adjust the vertical position of the catapult so the center of the ball lines up with the center of the bat.

9. Take some practice swings.
   a. Pull the catapult arm back, place the ball on the tee, and release the bat, as shown in Figure 12. Watch closely to make sure the bat hits the ball straight on. If it does not, go back to step 8 and realign your catapult and tee.
   b. You may need to reset the tee if it gets knocked over. Take a couple of practice swings to make sure your setup is working properly. Try different swing angles and tee positions.
   c. Practice reading the *swing angle* from the marks printed on the metal disc (see Figure 13, below). This is the angle the bat swings through before it comes to a stop. Try releasing the bat from several different swing angle positions.
   d. If you are having trouble hitting the ball consistently, make any necessary adjustments to your tee or the clamped position of your catapult before continuing.

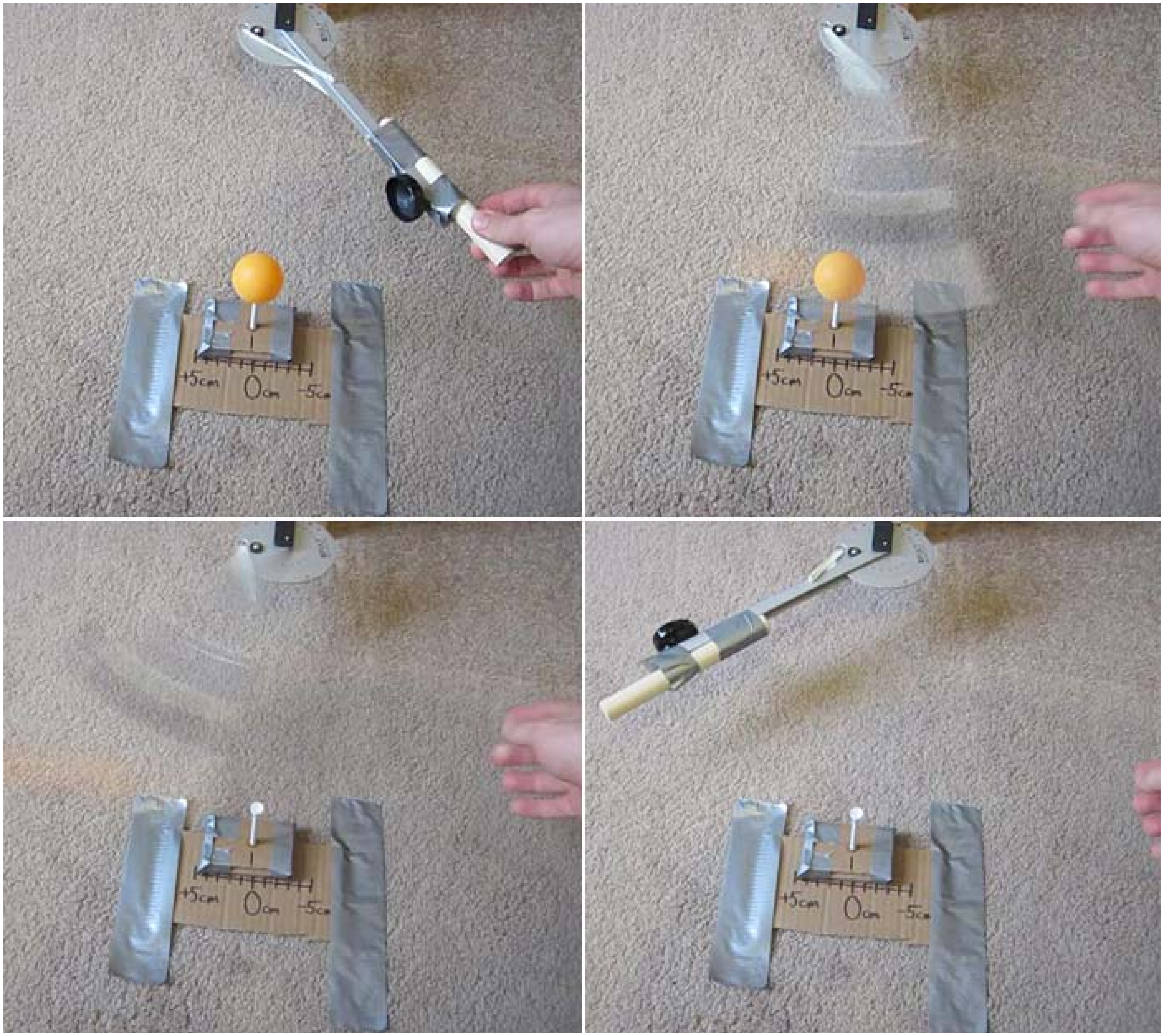

Figure 12. Pull the catapult arm back and release it to hit the ball. This figure shows four frames from a video of the ball before and after being hit.

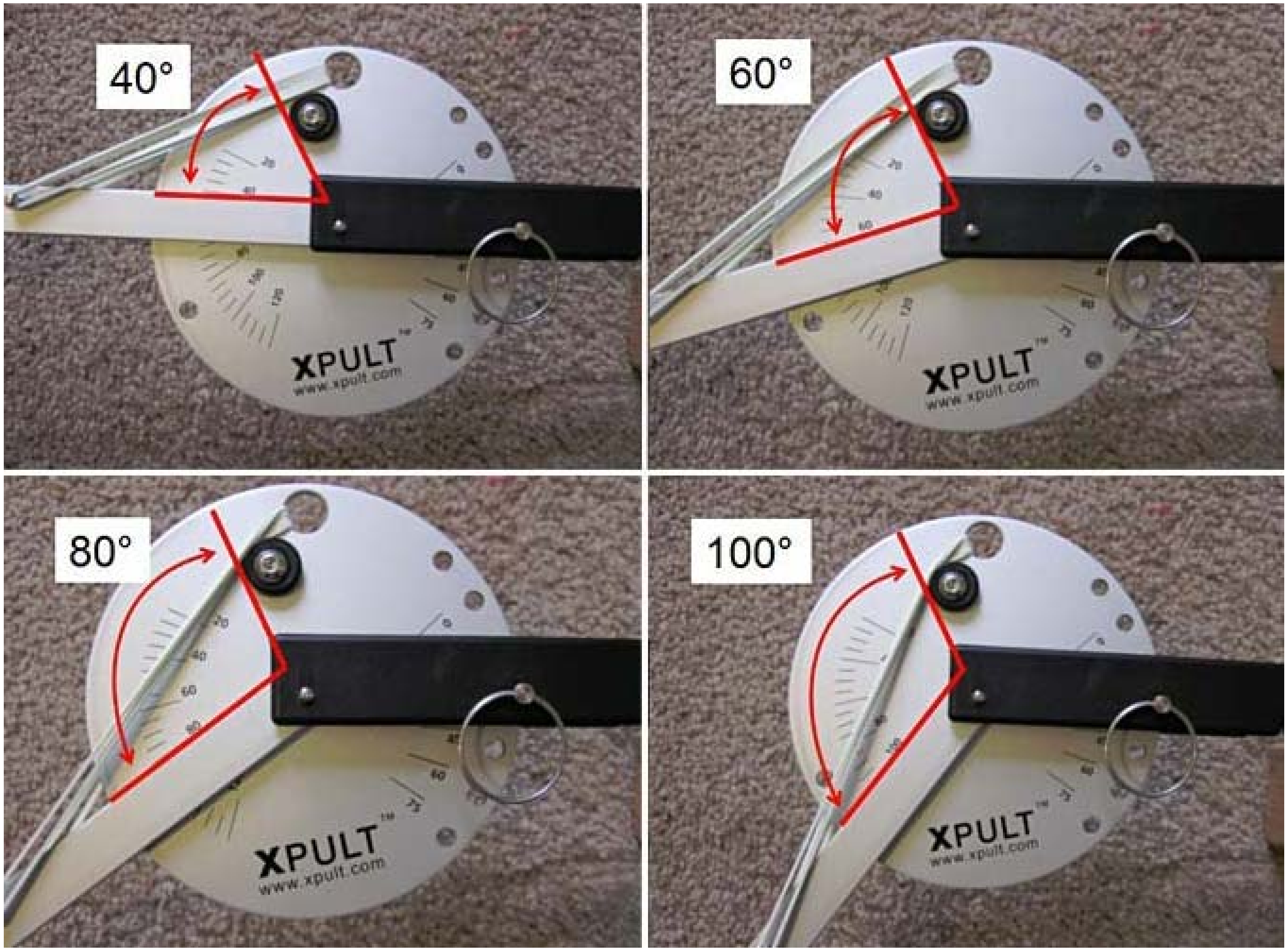

Figure 13. Use the markings on the metal disc to measure the swing angle. The swing angle is the angle the bat travels from when it is pulled all the way back until it hits the rubber stopper, *not* the angle it travels until it hits the ball. Make sure you take your angle reading from the *front* edge of the catapult arm, not the back.

Collect Data

1. Make a data table like Table 1, below, in your lab notebook, or use a spreadsheet program like Microsoft Excel® if available (this will make it easier to plot your data later).
    a. You should pick a series of tee positions (for example -5, -4, -3, -2, -1, 0, +1, +2, +3, +4, and +5 cm) and swing angles (for example 80°, 100°, 120°) to test, and do at least three trials for each possible combination. If you have extra time, you can pick more combinations (for example, test angles every 10° instead of every 20°), or you can do more trials (for example, five or ten trials instead of three).
    b. *Important*: You may need to adjust the swing angles you use depending on the amount of space you have available. Only use swing angles that keep the

ball inside your available space (i.e., exclude swing angles where balls keep hitting walls or other objects).

c. *Note*: In baseball, distances are measured using English units (feet). However, scientists always use metric units. For this science project, you should measure distance in metric units. For example, measure your tee position in centimeters, and the distance the ball travels in meters.

Trial	Tee Position (centimeters)	Swing Angle (degrees)	Ball X Position (meters)	Ball Y Position (meters)
1	-5	80		
2	-5	80		
3	-5	80		
4	-5	100		
5	-5	100		
6	-5	100		
7	-5	120		
8	-5	120		
9	-5	120		
10	-4	80		
11	-4	80		
12	-4	80		
...	...	...		

Table 1. An example data table. The table is not filled out completely — you will need to add rows for each combination of settings discussed above.

2. Collect your data.
    a. Starting with the first row of your data table, set the tee position and pull back the catapult arm to the swing angle.

b. Carefully place the ball on the tee, then release the catapult arm to hit the ball. Wait for the ball to come to a complete stop.
c. Use a tape measure to record the *X* (left/right) and *Y* (forward) position of the ball, as shown in Figure 14, below.
   i. *Important*: The diagram in Figure 14 represents a **coordinate system**. In order for your measurements to be consistent for each trial, the **origin** (or point where X = 0 and Y = 0) of the coordinate system must remain the same. Here, we choose the "0" mark on your cardboard ruler as the origin. Always make sure that you take your measurements from this "0" mark, *not* from the current tee location. For example, if the tee is currently set at the +2 cm mark, you would still start out your measurement for the Y direction at the 0 cm mark on your ruler.
   ii. *Important*: You need to measure the X and Y distances separately, so you can make a plot of the ball's position later. Do *not* just measure the straight-line distance from the origin to the ball.
   iii. *Optional*: If it will help you make more accurate measurements, try laying out pieces of string, tape, or wire on the ground to line up with your X and Y axes, as they are shown in Figure 14. This may help you make sure that your X and Y measurements are always *perpendicular* to each other.

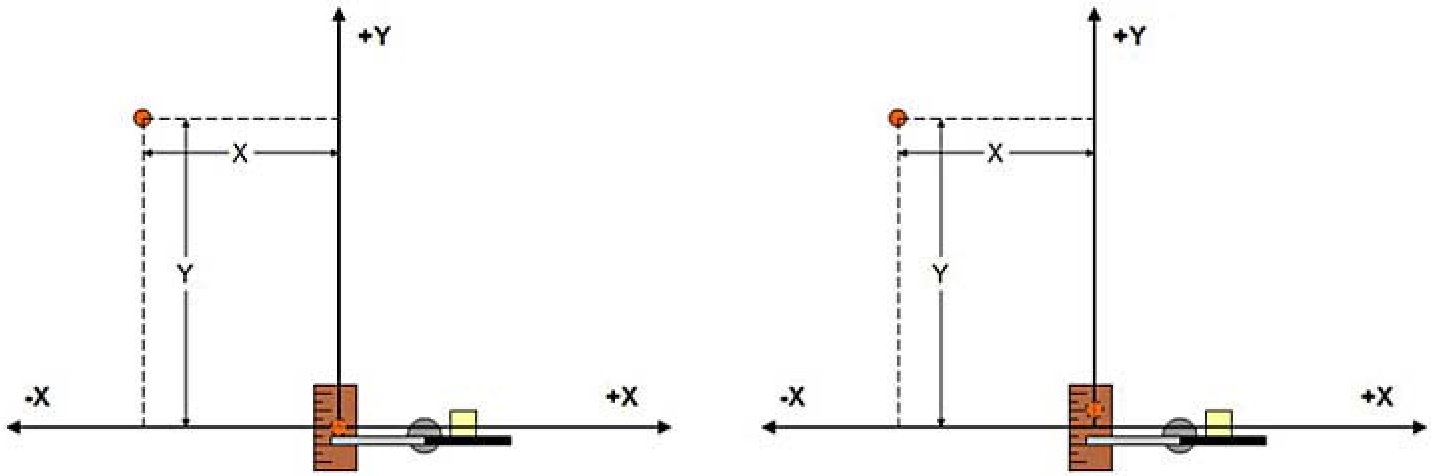

Figure 14. The coordinate system used to measure the X and Y location of the ball after it comes to rest. Notice how in the image on the left, the tee is placed at the *origin* of the coordinate system. In the image on the right, the tee has been moved to a different position, but the *origin of the coordinate system stays in the same place*. This is very important.

3. Repeat step 2 for each row of your data table. Remember that if you have time, you can always do extra trials or try new settings and add those to your data table.
4. Make two separate scatter plots of your data using the X and Y position columns of your data table.
   a. Color-code one plot by tee position.
   b. Color-code the other plot by swing angle.
   c. *Note:* Do not forget to add a legend to each plot, explaining what the colors represent.
5. Analyze your results.
   a. How does tee position appear to affect where the ball goes? Does it have an obvious impact on either direction (left, right, or center field in the imaginary baseball field that your experiment represents) or distance (how far the ball goes from "home plate," the origin of your coordinate system), or both?
   b. How does swing angle appear to affect where the ball goes? Does it have an obvious impact on either direction (left, right, or center field) or distance (how far the ball goes from home plate), or both?

6. The experiment you set up in this project is a simplification of a real baseball swing. How, if at all, do the variables you tested in this experiment relate to what happens during a real baseball game? Could you suggest some changes so your experiment would represent the real situation better? Here some questions to get you started:
   - In a real game, the ball is pitched; in this experiment, you hit the ball off a tee. How could that affect your experiment?
   - In real baseball, players sometimes hit the ball in an upward arc, and not straight out. How would this make your results different?
   - In a real hit chart, the dots mark the location where the ball was *fielded* (caught or picked up by a defending player), not where it rolls to a stop. How do you think that affects the appearance of a hit chart?
   - What other variables could you not test in this experiment?

Frequently Asked Questions (FAQ)

FAQ for this Project Idea available online at https://www.sciencebuddies.org/science-fair-projects/project-ideas/Sports_p060/sports-science/physics-of-baseball-hit-charts#help (http://www.sciencebuddies.org/science-fair-projects/project-ideas/Sports_p060/sports-science/physics-of-baseball-hit-charts#help).