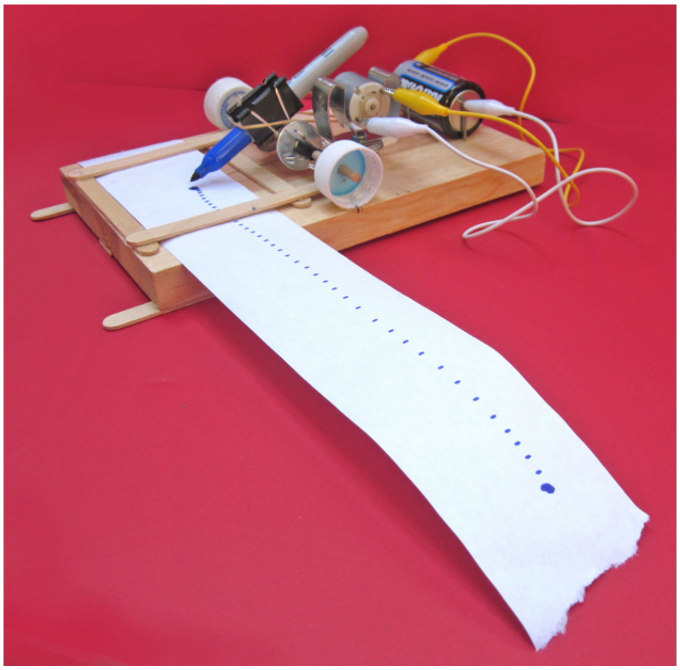
Paper Tape Motion Timer

Timing is Everything!



Introduction

A strip of adding machine paper tape is passed underneath the tip of a marking pen that is being repeatedly bumped by a wooden dowel mounted off-center on the spinning shaft of an electric motor operating at constant speed. Every time the pen is bumped, it makes a mark on the paper tape. Since the motor speed is constant, the time interval between marks is constant. If the paper is dragged rapidly, the marks on the paper are far apart; if the paper is dragged slowly, the marks are close together. The resulting record of marks on the tape can be used to tell the story of the motion, create graphical representations of the motion, and obtain information about displacement, velocity and acceleration for things like toy cars, falling objects, etc.

Materials

• wood base, 3/4 in x 5 1/2 in x 9 in (a piece of "1x6" pine shelving that is 9 inches long)
• 4 finishing nails, 1 1/2 in
• hammer
• 7 wooden craft sticks (regular "popsicle stick" size, not jumbo)
• hot glue gun and hot glue sticks
• 2 bottle caps from 2-liter plastic soda bottles or other bottles with a similar cap

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• 1 bottle cap from a common 500 mL plastic water bottle -- the cap should be the slightly “softer” kind, not the “harder” kind typically found on 2-liter plastic soda bottles -- you'll need to be able to poke a pushpin through this cap
• electric drill
• drill bits -- 1/8 in, 3/16 in, 3/32 in
• hex nut, zinc-plated steel, ½"
• 5 fender washers, zinc-plated steel, 3/16" x 1 " (inner and outer diameters) -- small, unavoidable variations in location of components during the assembly process and in sizes of components will determine the exact number of washers needed
• spring clip broom holder (see photos) for motor mount (or improvised alternative)
• sheet metal screw, pan-head Phillips, #8 x 1¼"
• screwdriver, Phillips
• wood dowel, 1/2 in, 1 in long
• machine screw, pan-head Phillips, #4-40 x 1/2"
• motor, dc, 1.5volt - 6 volt – needs to fit in spring clip motor mount or improvised alternative
• binder clip, medium
• Sharpie marking pen, Fine Point -- other marking pens can be substituted if they can be held by the medium binder clip and the point will mark satisfactorily
• wood dowel, 3/16 in, 5 1/2 in long
• 4 binder clips, mini
• pushpin
• rubber band, #19 – or use other sizes and adjust tension accordingly
• 1.5 volt D battery
• 2 alligator clip leads, approximately 12 in long
• masking tape
• paper adding machine tape roll, 2 1/4 in wide
• pull-back or wind-up spring-powered toy car powerful enough to pull the tape through the timer (a battery-powered toy car may also work, but its motion is likely to be constant speed, which for the initial purposes here is not as interesting or instructive as non-uniform motion)

Assembly

A. Template

The following drawing shows locations and dimensions of items on the wood base. It will be referred to in the remainder of the Assembly section as the Template.
If desired, a **full-size** printed copy can be placed on the wood base and locations can be marked pn the base by poking through the paper with a pencil. Make sure that your particular printing process has actually printed full-size -- the board outline should be 5 ½"x 9" when physically measured on the printed copy.

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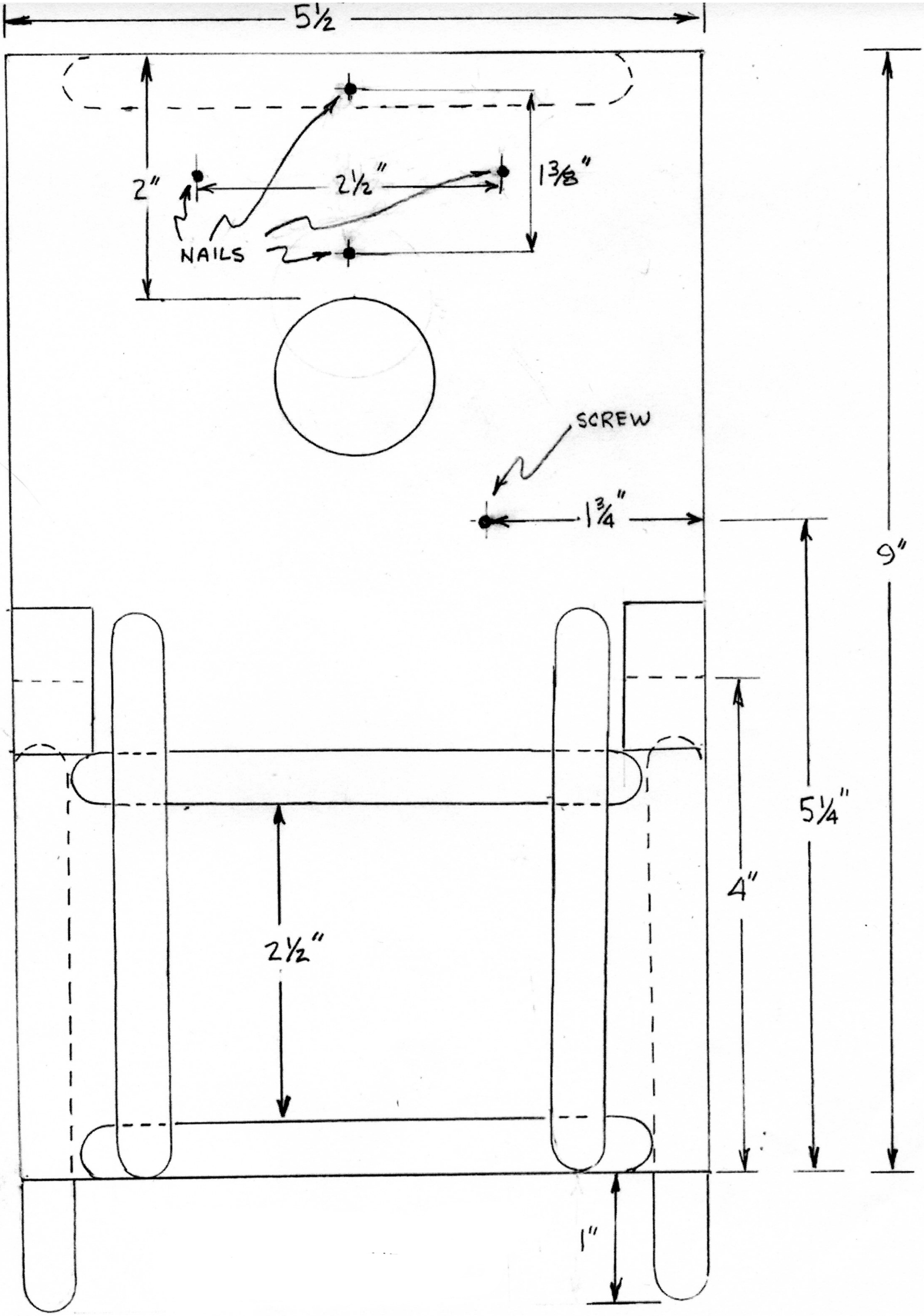
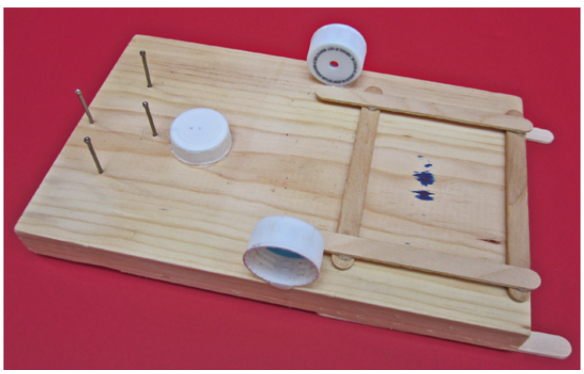


5½
2"
2½"
1⅜"
NAILS
SCREW
1¾"
9"
5¼"
4"
2½"
1"

B. Base

1. Glue three craft sticks to the underside of the base as shown in the photo below. The two tabs that protrude from the right edge in the photo should each be 1 inch long (see dimensions on Template).

Steps 2-5 all refer to the photo immediately below (click to enlarge). Actual dimensions for locations can be found on the Template.



2. Hammer the 4 nails for the battery holder.

3. Glue the single “soft” bottle cap to the base.

4. Drill a 3/16-inch hole in the center of each of the two “hard” bottle caps.

5. Glue the two drilled bottle caps to the base 4 inches from the end (see Template). The drilled portions should be on the inside (see photo above).

5. Glue 4 craft sticks to the top of the base. Note the 2 ½-inch distance between the inside edges of the two sticks which are glued directly to the base (see Template)

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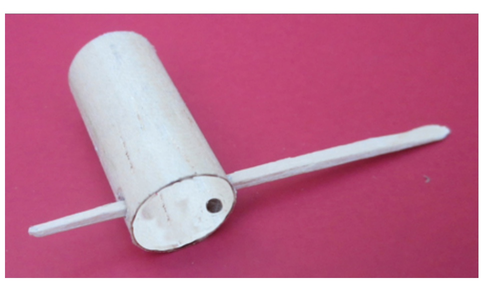
C. Motor Mount Assembly

1. Place the spring clip broom holder, 3 fender washers and the hex nut on the sheet metal screw to form the motor mount assembly, as shown in the photo below.

2. Use the drill and 1/8-inch drill bit to drill a pilot hole into the base at the location noted on the Template. Screw the motor mount assembly to the base at this location as shown in the photo below.

3. Drill an off-center hole in one end of the ½-inch dowel using the 3/32-inch drill bit. Then use the 3/32-inch drill bit again to drill a hole perpendicularly through the dowel so that the center of the hole is as close to exactly 1/8 inch from the end of the dowel as you can get it, and intersects the hole already drilled into the end of the dowel. The photo below shows the hole in the end of the dowel and a toothpick stuck through the perpendicular hole through the dowel. The toothpick intersects the other hole.



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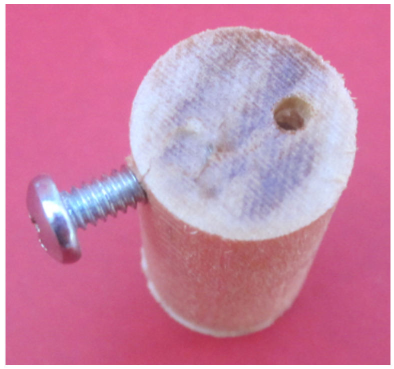
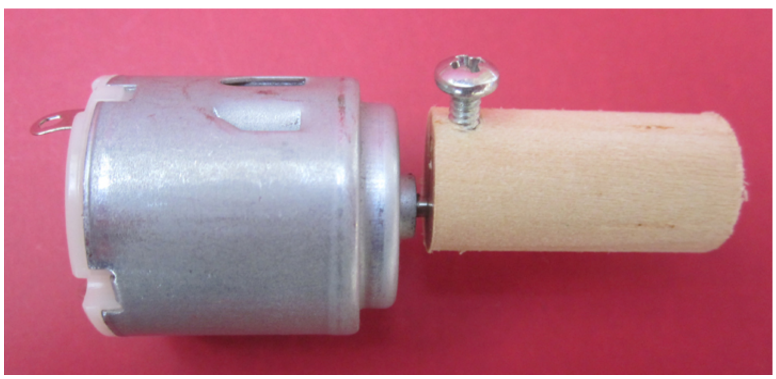
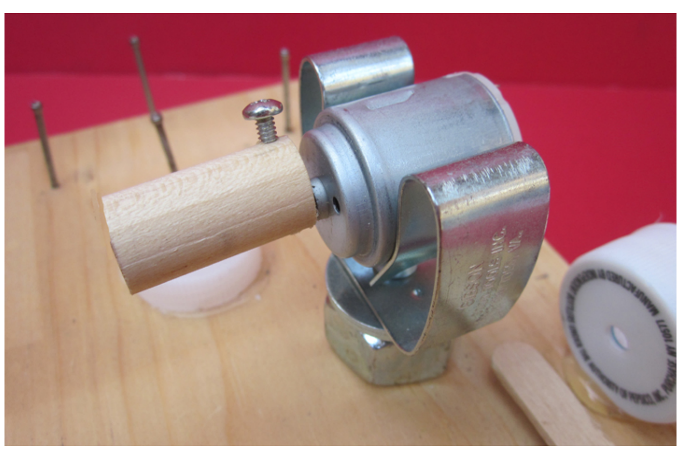
4. Screw the machine screw into end of the hole running through the dowel. Start it in the end of the hole that is farthest from the intersection with the other hole. Screw it in far enough so that it will stay in place, but not so far that it will reach the other hole. See photo below.



5. Slide the motor shaft into hole drilled in the end of the dowel as far as possible without the motor casing actually making contact with the dowel. Then tighten the machine screw so that its end firmly contacts the motor shaft and acts as a set-screw to keep the dowel from slipping off the motor shaft. See photo below.



6. Press motor into spring clip so that dowel is near middle of base. See photo below.



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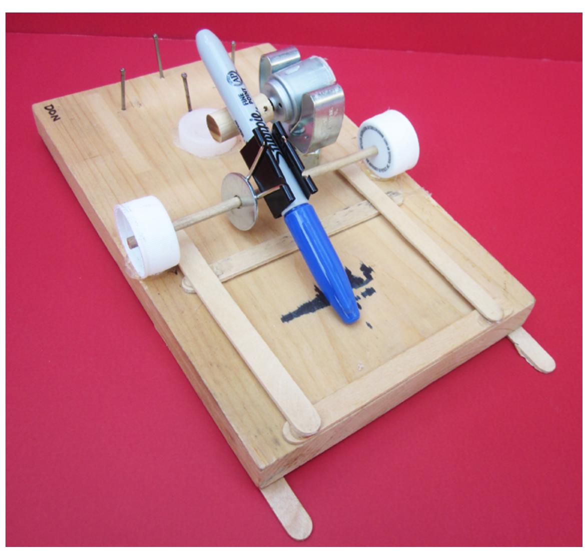
D. Pen Assembly

1. Use the hot-glue gun to apply glue in a U-shaped bead to one of the fender washers as shown (see first photo below). Then immediately press the handle of the binder clip into the glue before it cools (see second photo below). Allow to cool for a minute or so, and then repeat for the other handle.

2. Put pen in binder clip and put binder clip/pen assembly on 3/16-inch dowel, as shown in the photo below.

3. Insert the dowel in the holes in the bottle caps, as shown in the photo below.



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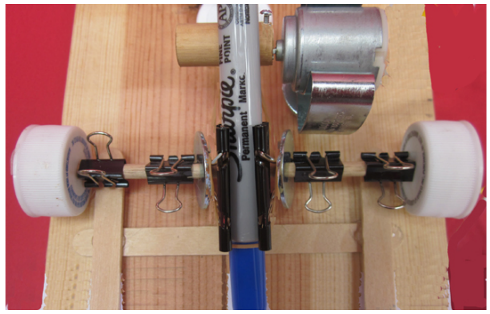
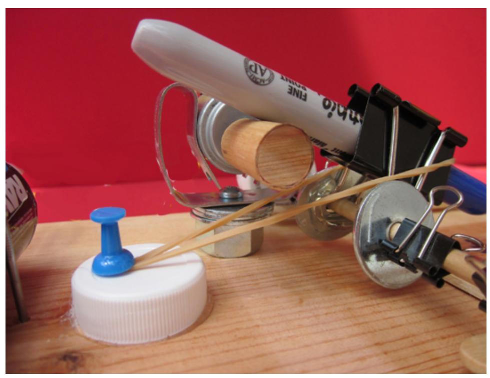
4. Put four mini binder clips on the dowel as shown in the photo below. Adjust to keep pen assembly from sliding sideways on dowel and to keep dowel from sliding sideways in mounting holes. Be sure the pen assembly is completely free to turn on the 3/16- inch dowel, and that the barrel of the pen rests on the ½-inch dowel in such a position that the set-screw does not hit the pen when the dowel is rotating.

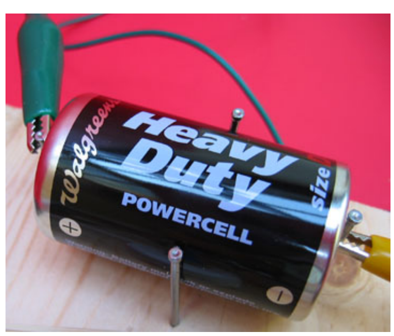


5. Put the rubber band in place around the pen/binder clip. Press the pushpin into the rear cap and put the rubber band in place around it. The pushpin may be moved to adjust tension in the rubber band if necessary. See photo below.



E. Try it Out and Make Necessary Adjustments

1. Put the battery in place.



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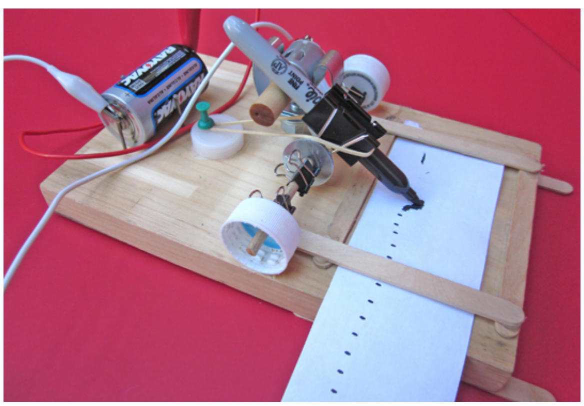
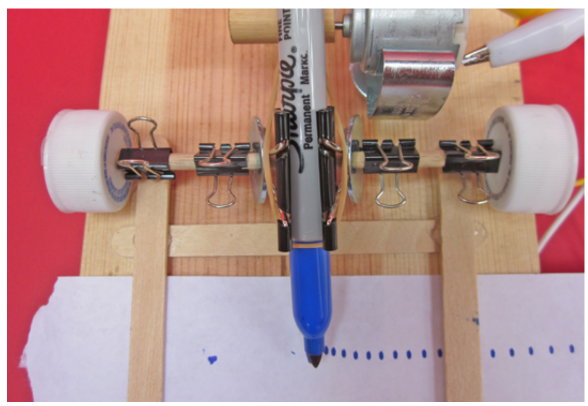
2. Take the cap off the Sharpie. Remember this for future use – it's easy to forget to do this. Also remember to put the cap back on the Sharpie when finished, or if you are going to be more than a few minutes between runs. If the Sharpie is left uncapped for a prolonged period it will dry out will have to be replaced with a new one.

3. Use masking tape to tape the protruding craft stick tabs of the timer to the table. Place a piece of adding machine tape about 2 ft long in the timer. Thread the paper tape through the craft stick paper guide so that it is under the tip of the pen, and one end is just past one of the timer edges.

4. Hook up the alligator clip leads to the motor and battery. You may get a cleaner mark when making tapes if you connect motor and battery so the dowel is turning clockwise as you look at its exposed end, but this may not always be the case and you are encouraged to try it both ways and use whichever direction gives the best result in your judgment.

5. Pull about a foot of paper tape through the timer at a speed where the marks become clearly separated. Inspect the paper tape to make sure that the pen is making distinct marks on the tape (see examples in the photos below).





If the marking is not satisfactory, try one or more of the following adjustment tips:

1) adjust the position of the dowel that hits the pen by slightly rotating the motor mount assembly

2) slide the pen forward or backward a little in the binder clip

3) unscrew the motor mount assembly and either add or remove fender washers as necessary (small differences in the brands of the grip-clip broom holders, or other variations in construction may occasionally require the height of the motor mount assembly to be raised or lowered so the dowel will hit the pen properly)

4) move the position of the screw hole for the motor mount assembly

Continue to run test tapes and make adjustments until the marks are satisfactory.

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To Do and Notice

Pull about two feet of paper tape through the timer, but pull the first foot or so slowly and then notably increase the speed of pulling for the remaining tape. What do you notice about the spacing of the marks when the tape was pulled slowly compared to the spacing when it was pulled faster?

What's Going On?

Every time the pen is bumped, it makes a mark on the paper tape. **The time between marks is always the same,** since the motor runs at constant speed. If the marks are farther apart, the larger distance just means that the tape was being pulled faster; if the marks are closer together, the smaller distance means that the tape was being pulled slower. The **distance between marks may vary,** but the **time between marks is constant.**

Going Further

You can now use the timer to record the motion of objects such as a spring-driven toy car or a falling object. Just use masking tape to attach the paper tape to the object whose motion you wish to record, and let the object pull the tape through the timer. The resulting record of marks on the tape can be used to tell the story of the object's motion, including creation of graphical representations of the motion, and information about displacement, velocity and acceleration involved in the motion.

Velocity-Time Graph for a Spring-powered Toy Car

Attach a paper tape to the spring-powered toy car with masking tape, and make a record of the car's motion as it first accelerates and then ultimately coasts to a stop.

Mark the start of the tape. Use an arbitrary time interval -- e.g., 3 "ticks" (a "tick" will be a single interval or space between successive marks on the tape) -- and mark the tape at these 3-tick intervals. Each 3-space section represents a velocity -- a distance which you can measure in cm, and a time of 3 "ticks." For convenience, we'll call each 3-tick interval a "tock." Each tock represents an equal amount of time. Cut the tape at each dividing mark, and place each section vertically, with one end along a horizontal base line. Place each successive strip to the right of the one preceding it. It's a good idea to number each tock.

See sample graph below.

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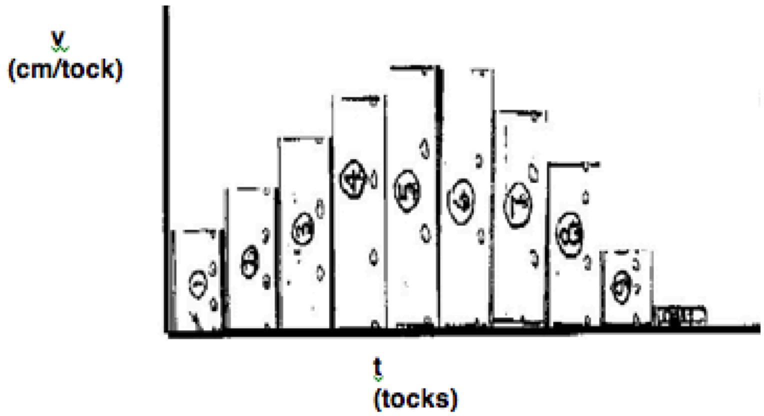
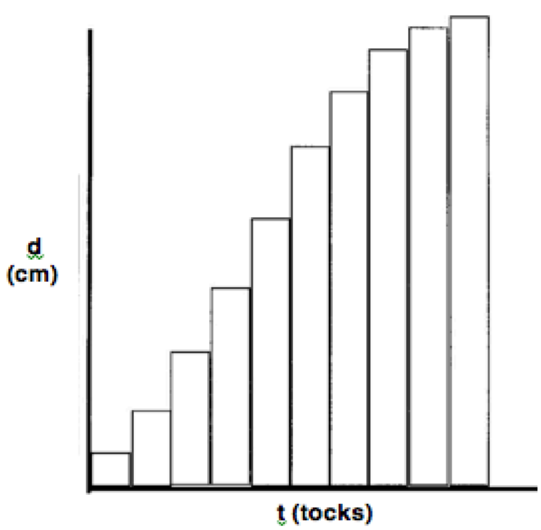


What you have made is a graph of velocity (vertical axis; units of cm/"tock") vs. time (horizontal axis; units of "tocks"). As the car accelerates, each successive section of tape gets taller, and as it slows down, each successive section gets shorter. At constant speed, the sections are the same height.

Displacement-Time Graph (for same tape as the Velocity section above)

Displacement represents how far the car is from its starting point. If all motion is in the same direction, as is the case with the car, then displacement and distance are identical. The displacement-time graph for the car's motion shows the **TOTAL (CUMULATIVE)** distance from the starting point for successive time increments (**NOT** just the distance traveled **during** the particular time increment, as was the case with the velocity graph). Using measurements of the lengths of the sections in the velocity-time graph, cut new strips of appropriate length (each successive strip will represent the sum of all strips to date; another way of saying this is that each strip will represent the sum of the previous strip plus itself) and make a displacement-time graph for the same car trip.

The sample graph below shows the general shape of the resulting graph.



The story that the graph tells is that as time progresses, the displacement always gets greater, since the car gets farther and farther away from the starting point. Displacement never decreases in this example, because the toy car never travels backwards. When the car slows down, the displacement still increases, but at a slower rate.

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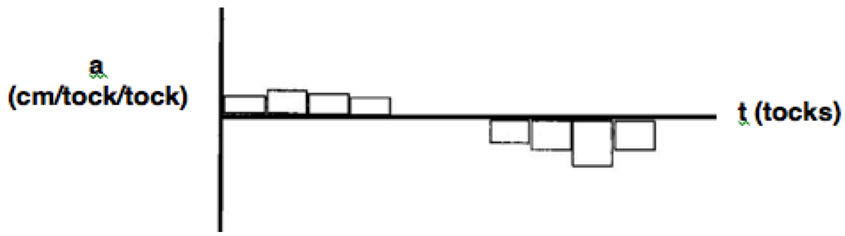
Acceleration-Time Graph (for same tape as the Velocity section above)

Acceleration represents change in velocity per unit time. An acceleration-time graph shows how much the velocity is changing during each time unit. Using measurements of the **difference** of adjacent sections in the velocity-time graph, cut new strips of appropriate length from the roll of adding machine tape to make an acceleration-time graph for the same car trip. When the velocity graph is increasing (car speeding up), the acceleration is positive and the strips should be placed above the zero axis. When the velocity graph is decreasing (car slowing down), the acceleration is negative and the strips should be placed below the zero axis. When speed is constant, acceleration is zero, and there are no strips.

See sample graph below.



Timer Calibration

Turn the timer on, letting it run for a few seconds without pulling the tape so that a mark will be made at the beginning. Then pull the tape slowly through the timer for 5 seconds (as **exactly** as you can do this).

Count the total number of intervals.

To find the **frequency** of the timer -- that is, **the number of intervals per second** -- divide the total number of intervals by the number of seconds you pulled the tape.

To find the **period** of the timer **– t**hat is, **the time for one interval**, or seconds per interval -- divide 5 seconds by the total number of intervals**.**

Determining g

Use masking tape to attach a paper tape to a reasonably heavy object, such as a C or D battery (a very light object will be more subject to error due to friction of the tape passing through the timer). The drop should be at least the height of a normal table, and may be higher if you can conveniently find a longer drop. Make the paper tape the length of the entire drop. If feasible, you might consider tilting the timer on its end to minimize friction of the tape passing through the guides.

Start the timer and let the object drop, generating a record of motion on the tape.

Find the slope of the velocity-time graph in cm/tick/tick (cm/tick^2) or cm/tock/tock (cm/tock^2). This slope represents the acceleration of the falling object.

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Use your calibration results to perform a unit analysis conversion of the slope value from cm/tick^2 or cm/tock^2 to m/s^2. An example of such a conversion is shown below (the values used for frequency and slope are representative of actual data obtained with tape timers).

Calibration of timer (frequency) = 26 ticks/s

Slope of graph = 1.2 cm/tick^2

$$\frac{1.2\ \text{cm}}{\text{tick}^2} \times \frac{1\ \text{m}}{100\ \text{cm}} \times \frac{26\ \text{ticks}}{1\ \text{s}} \times \frac{26\ \text{tick}}{1\ \text{s}} = \frac{8.1\ \text{m}}{\text{s}^2}$$

While there is a notable error between the experimental value of 8.1 m/ s^2, and the accepted value of 9.8 m/s^2, the timer nevertheless illustrates the process quite elegantly, considering its simplicity, obvious potential sources of error and low cost. On occasion, values have been obtained that are quite close to the actual value.

Credit

This timer draws its inspiration from the PSSC Physics ticker tape timers of the 1950's and 1960's.

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