Paper Tape Motion Timer

Timing is Everything!

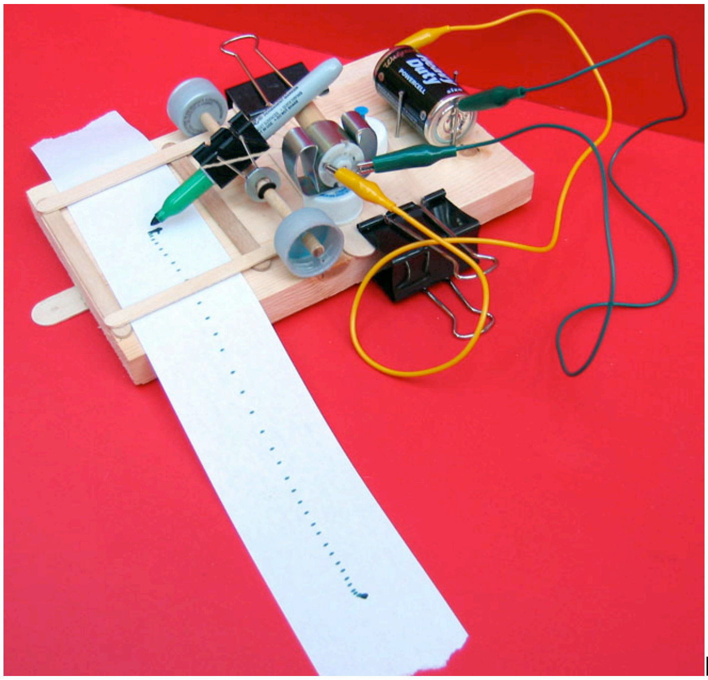

Figure 1

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 (in Home Depot terms, a piece of "1x6" pine shelving that is 9 inches long)
- 4 wooden craft sticks (popsicle stick size)
- 2 wooden craft sticks (tongue depressor size)
- hot glue gun and hot glue sticks
- paper adding machine tape, 2 1/4 in wide
- motor, dc, (e.g., Radio Shack 273-223, 1.5-3 v, or Kelvin 850647 1.5-6 v – Kelvin is cheaper, but Radio Shack is more accessible)
- 2 alligator clip leads -- e.g., Kelvin 330114, 10/pack, or Radio Shack 278-1157, 8/pack – or can improvise by using ordinary hookup wire (approximately #20 or #22), twisting ends to make connections, and devising some way to conveniently connect and disconnect the motor
- spring clip broom holder (available from Home Depot and other home improvement and hardware stores)
- machine screw, 6-32 x 1/2 in
- screwdriver, Phillips
- electric drill
- stop nut w/ nylon insert, 6-32
- 2 washers, ordinary zinc-plated steel, 1/4 in
- drill bits -- 3/16 in, 9/64 in, #50 wire gauge (1.78 mm)
- 3 bottle caps from 2-liter plastic soda bottle, or other bottles with same kind of cap -- the caps should be the harder, rigid plastic kind, not the softer, more flexible kind typically found on 500 mL water bottles
- 1 bottle cap from 500 mL water bottle, or other bottles with same kind of cap -- the cap should be the softer, more flexible plastic kind, not the harder, rigid kind typically found on 2-liter plastic soda bottles
- 2 binder clips, large (2 in, 51 mm)
- 2 binder clips, medium (1 1/4 in, 33 mm)
- push pin
- 2 rubber bands, narrow, approx 3 1/2 in, e.g., size 19
- 1.5 volt D battery

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• wood dowel, 1/2 in, 1 in long
• wood dowel, 3/16 in, 5 1/2 in long
• marking pen (e.g. Sharpie Fine Point) with pointed or bullet (not chisel-point) tip, and body size that can be held by a medium binder clip
• 2 faucet washers, size 1/4L flat, or similar -- the washer must have a center hole that will fit snugly on a 3/16 in dowel (see Figures 3b and 3c) -- many common faucet washers will do this
• hammer
• 4 finishing nails, 1 1/2 in

Assembly Photos, Notes and Comments

probably best to hammer nails for battery holder before putting other items on the board -- see Figures 1, 5 and 6 for location

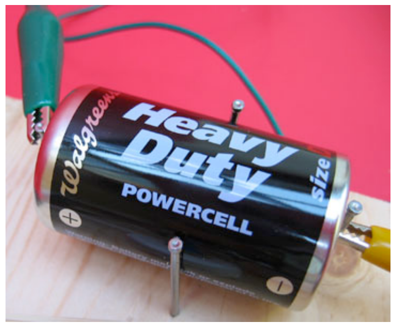

Figure 3

adjust washers so unit is held in middle of axle, but is completely free to turn on axle

assemble components as shown in Figures 3a,b,c, -- glue bottoms of end caps to board 4 in from end of board -- see Figure 6 for labeled location

Figure 3a

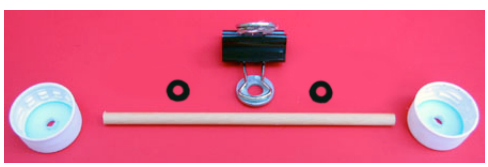

Figure 3b

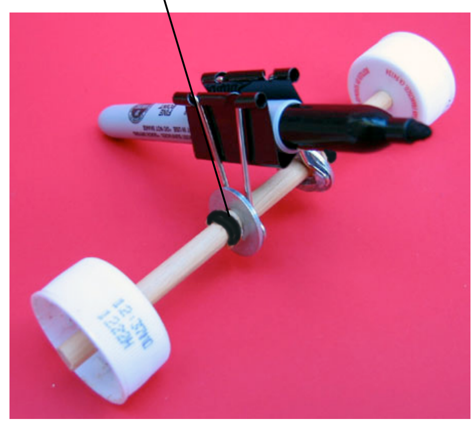

Figure 3c

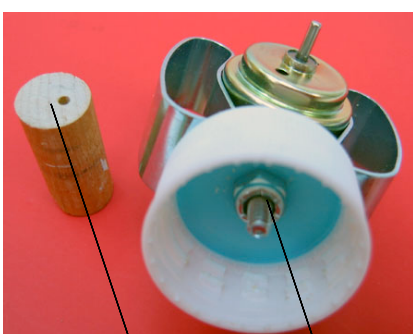

Figure 4a

#50 wire gauge (1.78 mm) hole drilled off-center

stop nut with nylon insert

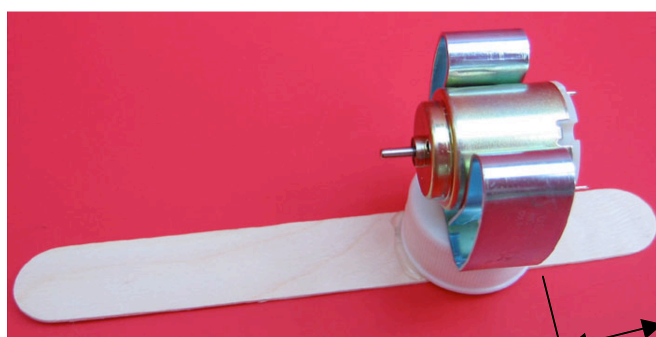

Figure 4b

1 in

glue bottom of cap to tongue depressor -- edge of cap (not visible) should be 1 in from end of tongue depressor

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when gluing these sticks, leave enough room between outside edge of stick and edge of board so that the bottle caps can fit

glue bottle cap to board so that edge shown is 2 in from edge of board

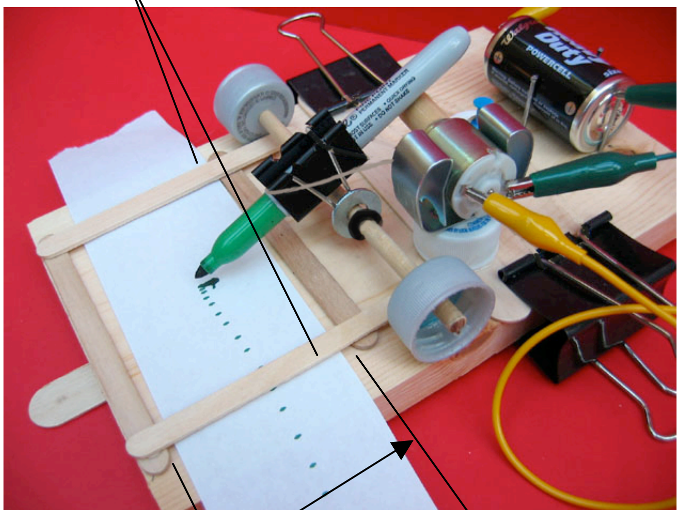

Figure 5

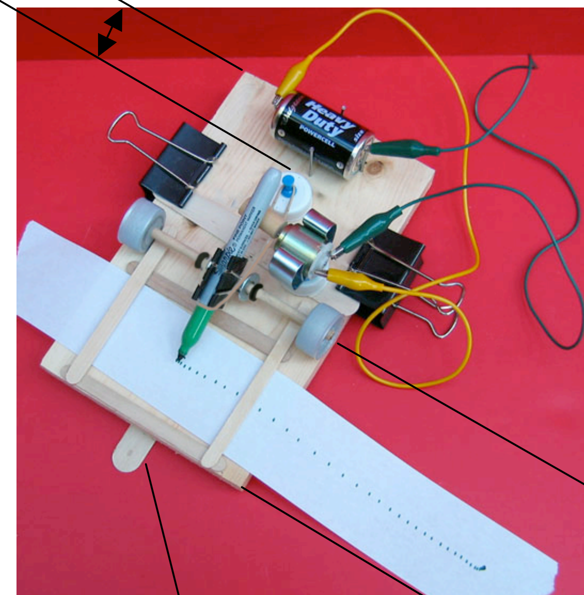

Figure 6

2 1/2 in between inside edges of sticks to handle 2 1/4 in adding machine tape

leave 1 in exposed so timer can be taped to table

pen assembly 4 in from end of board

you may get a cleaner mark if you connect motor and battery so dowel is turning clockwise as you look at its exposed end

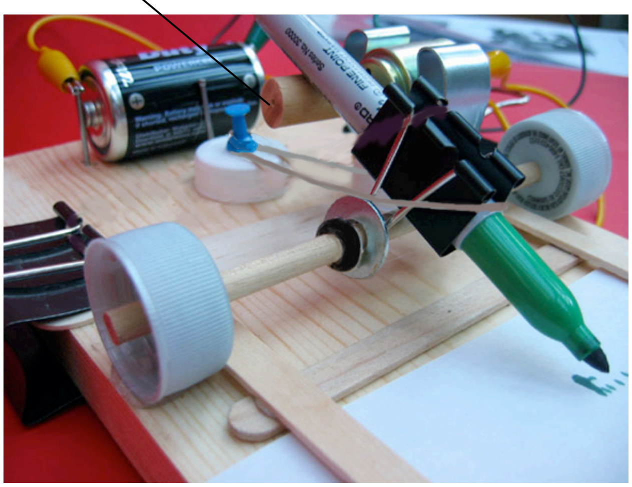

Figure 7a

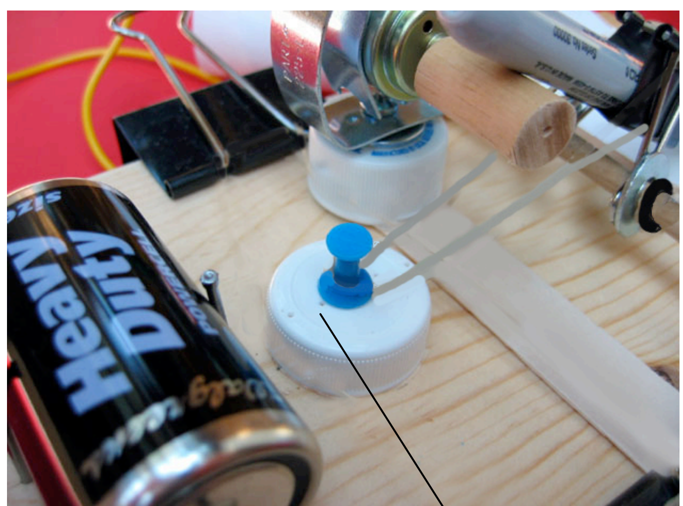

Figure 7b

push pin may be moved to adjust tension in rubber band if necessary

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To Do and Notice

1. Place a piece of adding machine tape about 3 ft long in the timer. Thread the paper through the craft stick paper guides.
2. Turn on the timer and slowly pull the paper a few inches. Inspect the paper to make sure that the pen is making distinct marks on the tape (see an example of a tape in Figures1, 5 and 6). If it doesn't, adjust the position of the tongue depressor that has the motor mount on it, and/or adjust the position of the dowel that hits the pen by turning the whole broom holder motor mount assembly.
3. Continue to run test tapes and make adjustments until the marks are satisfactory.
4. You can now use the timer to make a record of motion which will allow you to do such things as determining the displacement, velocity, and acceleration of a toy car and finding the acceleration of a freely falling object (i.e., the value of "g"). 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.

Motion Graphs for a Spring-Driven Toy Car

Attach a paper tape to a spring-driven toy car with masking tape, and make a record of the motion as the car accelerates and then coasts to a stop. A reduced copy of an actual tape is shown in Figure 8 (the original tape has only the the dots -- the vertical lines and numbers are added as discussed in the following paragraph).

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. It's a good idea to number each tock, as shown.

Figure 8

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. See Figure 9.

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.

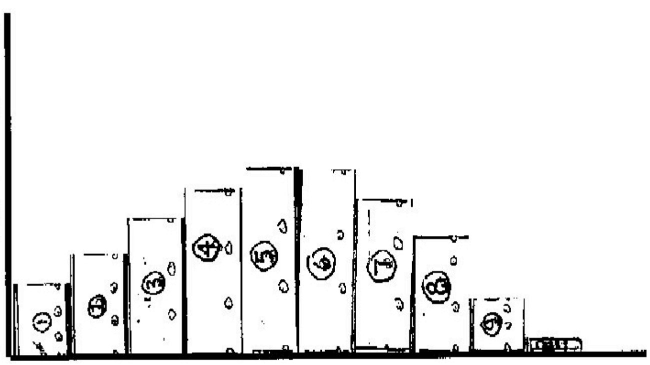

Figure 9

The sections that follow will show how to construct displacement and acceleration graphs, using information from the velocity graph.

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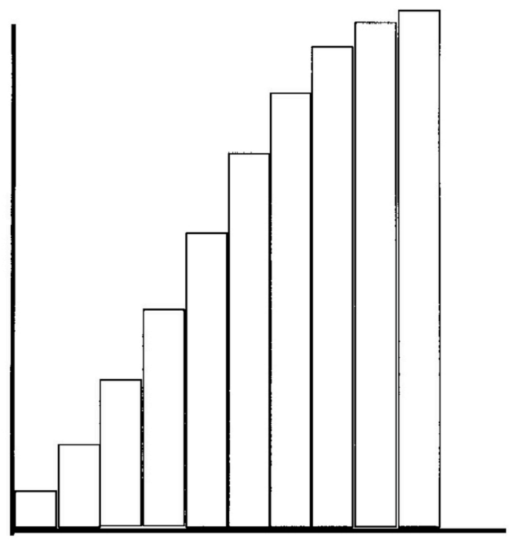
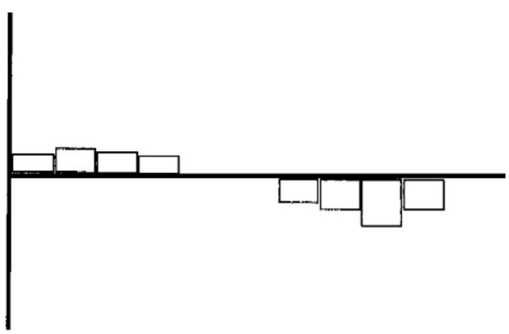


For the displacement graph, cut a strip of blank tape for each tock. The first displacement strip will be equal to the length of the strip for tock 1 in the velocity graph. The second displacement strip will be the sum of the strips for tocks 1 and 2 in the velocity graph. The third displacement strip will be the sum of the strips for tocks 1,2,and 3 in the velocity graph. And so on. The final displacement strip will be the sum of all the strips in the velocity graph. (NOTE: the displacement graph in Figure 10 is shown at a smaller scale than the velocity graph, since the height of a full-scale graph would require almost a whole page). When assembled as shown in the displacement-time graph in Figure 10, the story that the graph tells is that as time progresses, the displacement (distance from the starting point) 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, shown by the flattening out of the displacement graph near the end.

Figure 10

Figure 11



For the acceleration graph, you will again cut a strip of blank tape for each tock. The first acceleration strip will be equal to the length of the **difference** between the strips for tocks 1 and 2 in the velocity graph. The second acceleration strip will be equal to the length of the **difference** between the strip for tocks 2 and 3 in the velocity graph. The third acceleration strip will be equal to the length of the **difference** between the strips for tocks 3 and 4 in the velocity graph. And so on. (NOTE: the acceleration graph in Figure 11 is shown at a smaller scale than the velocity graph). The strips in the acceleration graph above the zero axis at the beginning represent positive acceleration, or speeding up of the car. The blank in the middle of the Figure 11acceleration graph represents zero acceleration, or constant velocity. The strips in the acceleration graph below the zero axis at the end represent negative acceleration, or slowing down of the car.

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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).

Starting at the beginning of the tape, draw a line through the first mark, and another line after each ten **intervals.** Count the number of 10-interval regions and multiply by 10, and then add on any remaining individual intervals. This will give the total number of intervals. (It's easier to keep track of things this way than by counting all the intervals individually, since there will likely be a large number.)

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 – that is, the **time for one interval, or seconds per interval --** divide 5 seconds by the total number of intervals.

NOTE**:** Remember that 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 is constant.**

Finding the Value of "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 side 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.

If the distance of the drop is short (i.e., table height), use a single tick as your time unit. If the drop is considerably longer, giving many marks on the tape, use a larger time unit, such as 3 ticks = 1 tock. Measure the distance in cm for each time unit (tick or tock). As in the earlier procedure for making a velocity-time graph, the distance you measure for each tock represents a velocity, in cm/tick, or cm/tock.

Make a velocity-time graph using your data.

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.

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) = 24 ticks/s

Slope of graph = 1.3 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 50's and 60's.

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SOME TIPS, NOTES, COMMENTS AND HELPFUL HINTS FOR THE PAPER TAPE TIMER

• Take the cap off the Sharpie before turning the timer on!

• Put the cap back on the Sharpie when finished, or if you are going to be more than a few minutes between runs! If you leave the Sharpie uncapped for a prolonged period it will dry out!

• The timer seems to operate better and make cleaner marks if you connect the motor and battery so the dowel is turning clockwise as you look at its exposed end.

• There are four ways to adjust the position of the motor-dowel assembly so that the Sharpie vibrates in the proper way. Use any or all as necessary:

1) adjust the position of the tongue depressor (or stack of tongue depressors if your timer has more than one) that has the motor mount on it by loosening the pressure on the two large binder clips and moving the tongue depressor

2) slide the pen forward or backward a little in the binder clip (the pen is held firmly; carefully twist and slide the pen to move it)

3) adjust the position of the dowel that hits the pen by rotating the broom holder-motor assembly

4) occasionally, small differences in the brands of the grip-clip broom holders used for motor mounts may require the use of a few additional tongue-depressor craft sticks as shims under the one to which the motor mount is glued -- this will raise the height of the motor assembly so the dowel will hit the pen -- the additional sticks don't need to be glued, but just inserted under the one with the motor mount

• The function of the tongue depressor that is glued to the bottom of the base and protrudes out about an inch is to allow the timer to be taped down. The bottom handles of the two large binder clips can also be used for this purpose. If you don't tape the timer down, it may move around or wobble while it's working, and results may suffer.

• Occasionally the dowel may work itself off the motor shaft after considerable usage. If so, just replace it (push it on the motor shaft as far as possible without hitting the motor casing). There is likely an alternate hole drilled in the opposite end, so if necessary, reverse the ends of the dowel and use the new hole.

• A 1/16 in. hole is slightly too small and a 5/64 hole slightly too big for the hole in the dowel. It's very hard to get the motor shaft in the smaller hole, and the larger hole may allow some slipping of the shaft in the hole after a time. A #50 Wire Gauge drill (1.78 mm) works very well -- it's between the two common sizes just noted. It's not a common size, but you can probably find it if you make an effort to look for it.

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