PRELAB: KINEMATICS LAB

1. The first tape shown below was made pulling it through the spark timer by hand.

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

   a) Briefly describe the motion of the person’s hand. Explain how you determined your answer.

   b) The marks at D were made later than the marks at C. How much later? (Assume the spark timer was set up according to the instructions in Investigation 1.)

2. How will the spacing between the marks on the first tape you will produce in Investigation 1 differ from the spacing between marks on the second tape in Investigation 1? Explain your answer.

3. Sketch predictions for the position-time and velocity-time graphs of the motion of the cart in Investigation 2 on the axes below. Indicate the moment your hand releases the cart on your graphs. (You may also want to copy these prediction graphs into your notebook before turning in this sheet). Explain the reasoning behind your prediction graphs in the space to the left of the axes.
Topic: Motion in one dimension

Overview:

You will be using a spark timer and long strips of spark paper (also called spark tape) to study the motion of various objects. The paper gets pulled past the two metal tips in the spark timer. When the spark timer is on, two spark tips zap the paper every 1/10 of a second (or every 1/60 of a second, depending on the setting you choose). Each time the tips zap the paper, a pair of black dots is produced.

The diagram above shows the spark timer and tape in action. When point A on the tape was underneath the spark tips, the timer was turned on and the person began pulling the tape to the left. As the hand moves to the left, so does the tape. One spark interval later (either 1/10 of a second or 1/60 of a second), point B on the tape was under the spark tips. Another spark interval later, point C was under the tips and so on. In this way, the spark tape makes a record of the motion of whatever the tape is attached to.

The dots provide a record of the position of the left end of the tape relative to the spark tips. For instance, when the dots at point C were made, the left end of the tape was a distance $x_C$ from the spark tips. Thus, the distance from the end of the tape is a measure of the position of the left end of the tape relative to the spark tips. For this lab, “position” refers to the position of the left end of the tape relative to the spark tips.

You might have noticed that mark A is darker than the other marks in the diagram. This happens when the tape does not start moving immediately when the timer was turned on. Several sparks were made at point A before the tape began moving.

Note: This lab involves repeated calculations and graphing. A spreadsheet program like Excel can drastically reduce the amount of work required to analyze the data.

Writing it up: Throughout this handout, you will be asked to answer questions, sketch graphs and do calculations. Write these things in your lab notebook as you go through the experiment. Label each answer/graph/calculation so that you (or your lab TA) can find things quickly. If you have any computer printouts (such as graphs), remember to affix them to your lab notebook. After lab, write a short (<300 words) conclusion of the experiment that summarizes what you did and the major findings of the experiment.
Investigation 1: Constant speed

In this investigation of the lab, you will examine what happens when you pull a tape through the timer at constant speed. You will make and interpret a position-time graph of the motion of your hand.

1. Set the spark timer to 10 Hz (10 sparks/s).
2. Pull a tape through the timer slowly and steadily. Try to keep the speed of your hand constant. Label the tape.
   Q1-1: Did your hand travel at constant velocity the entire time? How can you tell from the marks on the tape if your hand sped up? slowed down?
   Q1-2: Use your tape to estimate the average speed of your hand (during the time interval when the speed of your hand was roughly constant). Record your measurements and calculations in your notes.
3. Pull a second tape through timer steadily, but more quickly than before. Again, try to keep the speed of your hand constant. Label the tape.
   Q1-3: How did the marks on this tape differ from those on the previous one? Is this what you predicted in the prelab? If not, explain the discrepancy.
   Q1-4: Estimate the average speed of your hand during the time the hand was moving at constant velocity. Record your measurements and calculations in your notes.
4. For each of the two tapes you made, make a table of position versus time for the first twenty points or so. Graph both sets of data on the same set of axes. [Note: Use a spreadsheet, like Microsoft Excel, to save time.]
   Q1-5: Did your hand travel at constant velocity the entire time for both data sets? How can you tell from the graph if your hand sped up? slowed down?
   Q1-6: Compare the two traces on your graph. Which one corresponds to the fast pull? How can you tell from the graph?
   Q1-6: Find the equation \( y = a + bt \) that best fits the linear portion of each set of position-time data. What is the meaning of \( a \)? What are the units of \( a \)? How do you know? What is the meaning of \( b \)? What are its units? How do you know?
Investigation 2: Speeding up and slowing down

In this investigation, you will examine the motion of a cart as it speeds up and then slows down. You will make and interpret position-time and velocity time graphs.

Prediction: Sketch position and velocity graphs for the cart’s motion in your notebook.

1. Attach a tape to a cart. Turn on the spark timer. Give the cart a push. Allow the cart to slow down. Turn off the spark timer. You may need to do this a few times until you have a good tape that clearly shows the cart speeding up and then slowing down.

2. Make a table of your position-time data. Graph the data.
   
   Q2-1: Compare the shape of the position-time graph with your prediction. Point out similarities and differences. Explain any discrepancies between your prediction and the graph of the cart’s motion.
   
   Q2-2: When did the cart reach maximum speed? How can you tell from the graph?
   
   Q2-3: Use the position-time data to estimate the maximum speed the cart attained. Record your measurements and calculations.
   
   Q2-4: Choose a data point during the portion of the graph when the cart is slowing down. Estimate the speed of the cart had at the moment that mark was made. Record the calculation in your notes and explain the reasoning behind it.

3. Use the table of position-time data to generate data for a velocity-time graph. To do this you will need to estimate the velocity of the cart at each data point. Explain how you used the position-time data to find the velocity-time data in your notes. [Note: Excel can generate the velocity-time data from the position-time data quickly. You can write the appropriate formula in one cell and then use the “fill below” feature to perform the remaining calculations.]

4. Make a velocity-time graph.
   
   Q2-5: Compare the shape of the velocity-time graph with your prediction. Point out similarities and differences. Explain any discrepancies between your prediction and the graph of the cart’s motion.
   
   Q2-6: Can you tell from the velocity-time graph when the cart was speeding up? Slowing down? Explain.
   
   Q2-7: How does the velocity of the cart vary in time as the cart speeds up? Does it increase at a constant rate, or in some other way?
   
   Q2-8: How does the velocity of the cart vary in time as the cart slows down? Does it increase at a constant rate, or in some other way?
   
   Q2-9: Is there a portion of the velocity-time graph that is roughly linear? If so, find the equation \( v = b + ct \) that best fits the linear portion. What is the meaning of \( c \)? What are the units? What is the meaning of \( b \)? What are its units? Explain the reasoning behind your answers.
   
   Q2-10: Estimate the average acceleration of the cart when it was slowing down. Explain how you arrived at your estimate and comment on the reliability of the estimate.
   
   Q2-11: Estimate the average acceleration of the cart when it was speeding up. Explain how you arrived at your estimate and comment on the reliability of the estimate.
Analysis challenge: *If the acceleration is constant* during a part of the motion, the value of acceleration can be found directly from the position-time graph by using Excel’s fitting tools and interpreting the output. What type of equation best would fit the position-time graph if the acceleration is constant: $y = a + bt$, or $y = a + bt + ct^2$, or something else? Explain how you know which fit should work. Explain how you determine the acceleration from the equation. Compare the value you get to the value you found in step 4.

Investigation 3: Falling objects (time permitting)

In this optional investigation, you will examine the motion of falling objects with different masses.

1. Use the available clamps and rods to mount the spark timer to measure the acceleration of a falling object. Place a pad below the timer, so that the falling mass doesn’t damage the floor. Set the spark timer to 60 Hz.
2. Make tapes for several different objects, ranging in mass as much as practically (and safely) possible.
3. Plot the position-time data for all your data runs on a single graph.
4. Use the position-time data to calculate velocity-time. Plot the results on a single graph.

Q3-1: Does each mass speed up at a constant rate? Explain how you can tell.
Q3-2: Does every mass speed up at the same rate? Is this what you expected? Explain.
Appendix

Below is a close-up photograph of the spark timer. The paper gets pulled to the left (as indicated by the white arrow on the timer). The spark tips produce a spark at regular time intervals, making a pair of dots on the paper directly underneath the spark tips. (You can just see the copper spark tips through the timer’s transparent cover). The switch on the right selects the time interval between sparks (10 Hz = 10 sparks/s). As the tape is pulled to the left a series of spark marks is produced on the tape.