PHYSICS
MERCER UNIVERSITY

Linear Kinematics

Physics Lab III

Objective

This lab exercise will explore the relationships between distance, time, velocity, and acceleration. These relationships will be used to determine if the acceleration of a cart pulled by a hanging mass on a level track is constant.

Equipment List

Dynamics cart with track, two photogate timers and two Pasco Smart Timers, ruler, nylon string, hanging mass set, pulley.

Theoretical Background

Kinematics is the study of how objects move. The position, velocity, and acceleration of the object are used to describe how an object moves. The average velocity is defined as the rate of change of position in time:

$$v = \frac{x_f - x_i}{t}. \tag{1}$$

In this formula, v is the velocity of the object, x_f is the final position, x_i is the initial position, and t is the time interval as the position was changing from x_i to x_f.

Likewise, the average acceleration is defined as the rate of change of the velocity in time:

$$a = \frac{v_f - v_i}{t}. \tag{2}$$

In this formula, a is the average acceleration, v_f is the final velocity, v_i is the initial velocity, and t is the time interval in which the velocity is changing.

If the acceleration is constant, then the final position can be directly related to the initial position, initial velocity and the acceleration:

$$x_f = x_i + v_i t + \frac{1}{2} a t^2. \tag{3}$$

In this formula, the variables are the same as in the previous equations. Combining these equations to eliminate the time, the last kinematic formula is

$$v_f{}^2 = v_i{}^2 + 2a(x_f - x_i) \tag{4}$$

where the variables have the same meaning as in previous equations. In these equations, the arithmatic statement $x_f - x_i$ is sometimes replaced with the displacement term for $d = x_f - x_i$. Rearranging the equations puts them in a more standard form:

$$v_f = v_i + at \tag{5}$$
$$d = v_i t + \frac{1}{2} a t^2 \tag{6}$$
$$v_f{}^2 = v_i{}^2 + 2ad. \tag{7}$$

These are the standard equations used in linear, one-dimensional, kinematics.

Procedure

The photogate sail must be mounted on the cart before beginning the lab exercises. The photogate flag as shown in Figure 1 maintains a fixed position between the photogate heads. The photogate sensors detect the amount of time the sail blocks a continuous stream of light transmitted between the photogate heads.

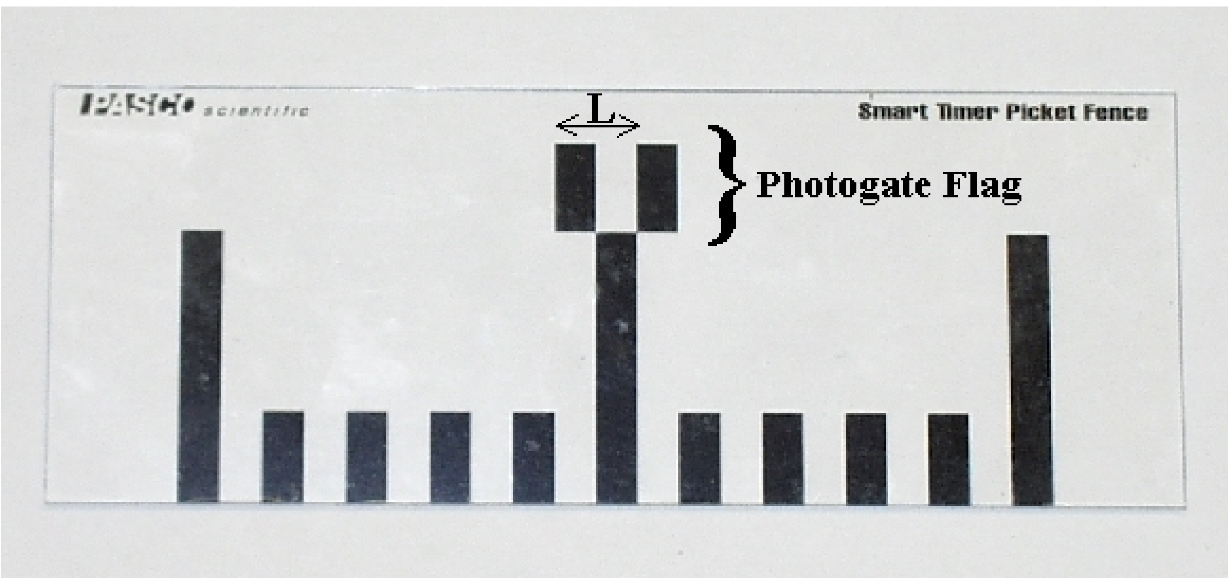

Figure 1: Photogate Sail with Flag

1. Set the photogates so that they are initially $20cm$ apart.

2. Set the height of each photogate so that the light sensor is approximately centered in the middle of the photogate flag. If you have trouble adjusting the height, inform your lab instructor.

3. Plug one of the photogates into the number 1 port of the Smart Timer. Again, plug the other photogate into the number 1 port of the other Smart Timer. The Smart Timer/photogate arrangement furthest from the pulley is henceforth denoted as ST 1 while the Smart Timer/photogate closest to the pulley is denoted as ST 2.

4. Tie a knot onto the hook of the hanging mass holder. Tie another knot into the hook of the cart with the same string. (This should have been done prior to the experiment.) Place 20 g on the mass holder. Record the total hanging mass of $25g$ which includes the 5 g mass holder.

5. Turn on both Smart Timers. Select the correct timing modes. Press the Select Measurement button twice. **Speed** appears on the LCD display. Press the Select Mode button once. **Speed:One Gate** now appears on the display. Repeat this process for the other Smart Timer. The timers are now set to the correct timing modes. The Smart Timers record the average speed the photogate flag of length L travels as it passes through the photogate light sensor (see figure 1).

6. Pull the cart back to the end of the track opposite the pulley. The string connecting the mass to the cart, when placed on the pulley, should be taut. Be sure the length of string does not exceed $120cm$. It may be necessary to shorten the length of the string connecting the mass to the cart.

7. Choose a release point for the cart. Measure this from the front edge of the cart. **Take note of this release point, since you will want to release the cart from this position throughout the lab exercise.**

8. Press the **Start/Stop** button on each Smart Timer. An asterisk (*) now appears below the **Speed:One Gate**. Release the cart. Be sure the cart goes through both photogates before the hanging mass hits the floor since the mass no longer accelerates after it hits the floor.

9. After the cart has gone through both photogates and the hanging mass has fallen to the floor, the timers should indicate the average speed of the cart travelling through each photogate. ST 1 displays the initial average speed, $v_{i\ exp}$ data, and ST 2 displays the final average speed $v_{f\ exp}$ data. Record this on your data table. If data is not displayed on one or the other or both Smart Timers, inform your lab instructor. Note, the Smart Timers give the units for average speed as cm/s. **Be sure to convert to the SI units of m/s before recording values.**

10. Unplug the photogate in ST 2 and plug it into the number 2 port of ST 1. Press the red Select Measurement button until **Time:** appears on the readout. Press the blue Select Mode button until **Time:Two Gates** appears on the readout.

11. ***After resetting the photogates and the timers, move the cart back to the original release point***. Press the black Start/Stop button until an asterisk (*) appears under the **Time:Two Gates**. ST 1 is now set to measure the total transit time, $t_{transit}$ of the flag travelling between the two photogates.

12. Release the cart, and record the transit time on the displayed on the timer.

13. After recording the time measurement, move the cart back to the release point. Press the red Select Measurement button until **Accel:** appears on the readout. Press the blue Select Mode button until **Accel:Two Gates** appears on the readout. Press the black Start/Stop button and an asterisk (*) should appear under the **Accel:Two Gates**. The photogates are now set to measure the average experimental value of the acceleration of the cart between the photogates, a_{exp} in cm/s^2.

14. Release the cart and record the average experimental acceleration data on your data table. **Be sure to convert the displayed value to SI units of m/s^2 when you record data.**

15. Adjust the separation distance between the photogate heads. Unscrew the knob of the track post supporting the photogate of ST 2 and move the post $5cm$ further away from the other track post. The total separation distance between the two posts is now $25cm$. **Be sure to keep the position of the other track post fixed; NEVER MOVE IT!!!**

16. Repeat steps 5 through 15 to obtain data for average speed, transit time, and acceleration for gate separations of 25cm, 30 cm, 35 cm and 40 cm **Be sure to release the cart from the release point established in step 7!!!**

17. Estimate the uncertainty of each experimental quantity listed on the data table. Record the smallest measured value for each given experimental quantity. Use these values to calculate the percent uncertainty of each experimental quantity using

$$\%\ uncertainty = 100 \times \frac{measurement\ uncertainty}{smallest\ measured\ value}. \tag{8}$$

18. After calculating each percent uncertainty, record the largest percent uncertainty for the experiment.

Data Analysis

1. For each value of the photogate separation, with accompanying initial and final velocity and the transit time between the gates, calculate the acceleration of the cart using,

$$a_{theo\ 1} = \frac{v_{f\ exp} - v_{i\ exp}}{t_{transit}}. \tag{9}$$

2. For each value of the photogate separation, with accompanying initial and final velocity, calculate the acceleration of the cart using

$$a_{theo\ 2} = \frac{{v_{f\ exp}}^2 - {v_{i\ exp}}^2}{2d}. \tag{10}$$

3. Calculate the percent difference between each average theoretical acceleration and each average experimental acceleration.

4. Calculate the percent variation of the experimental acceleration.

5. **Plot** the measured final velocity ($v_{f\ exp}$) as a function of the transit time between the two gates ($t_{transit}$). Draw the straight line that comes closest to these data points and determine the slope and y-intercept of this line.

6. Use the Final Velocity as a function of the Transit Time plot to calculate the area under the curve in the following manner. Draw a vertical line from each measured transit time value to the plotted line. You should have a total of 5 trapezoids. Measure the area by counting the total number of small squares within each trapezoid. For example, count the total number of squares of the trapezoid consisting of the following sides: the x-axis, the y-axis, the vertical line drawn from the first transit time and the plotted line. (Note, this area is a composite of the distance travelled from the initial time of 0 *sec* to the first total transit time. You will need to add this value to the area of each subsequent trapezoid.) Once you have totaled the number of squares for each time interval, multiply the value by the horizontal and vertical lengths of each small square. Consult with the lab instructor or lab TA if you have trouble.

7. The area under the $v(t)$ graph for each data point should correspond to the distance travelled by the cart. Calculate the percent difference between the area under the curve for each transit time value and the distance travelled between photogates.

8. **Plot** the measured final velocity squared (${v_{f\ exp}}^2$) as a function of twice the photogate separation (2d). Draw the straight line that comes closest to the data points and determine the slope and y-intercept of the line.

Selected Questions

1. What effect does friction have on the measured times, velocities, and accelerations? Does this effect introduce systematic or random error into the experiment?

2. What effect does variation in the release point have on the measured times, velocities and accelerations? Does this effect introduce systematic or random error into the experiment?

3. Consider the acceleration values for each separation distance. What is the variation between the acceleration values? In other words are the acceleration values constant or variable? Briefly explain why you would expect the acceleration values to be either constant or inconstant.

4. Under what circumstances would an object have zero acceleration and nonzero velocity? Give an example. Under what circumstances would a object have zero velocity but nonzero acceleration? Give an example.