NEWTON'S SECOND LAW

Objective

To investigate the relationship between force and acceleration in linear motion.

Equipment

Balance, PASCO cart and track, bubble level, 1.1-meters of string w/ paperclip (or rubber band), timer w/ 2 photogates, 4-10g and 1-20g masses, pulley, plastic "picket fence".

Introduction

According to Newton's second law, the acceleration of a mass is proportional to the net applied force. In this experiment you will apply a force to a rolling cart on a linear track and measure the time it takes for the cart to move a specified distance.

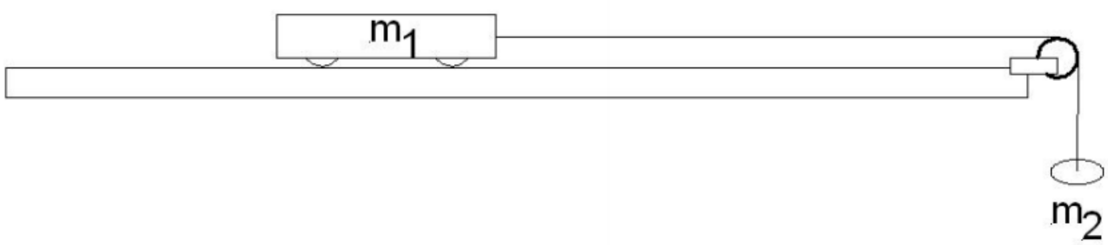

Figure 1: A linear track showing a cart (with mass m_1) attached by a string passing over a pulley to another mass m_2.

Gravity acts on mass m_2 with a force $F = m_2 g$. (See Figure. 1). That force then accelerates both m_2 and m_1. (The mass of the string may be neglected here.) Consequently, the acceleration of the cart (and the small mass m_2) is the ratio of the applied force to the total mass:

$$a = \frac{F}{m_1 + m_2} \tag{1}$$

The mass of the string and the friction in the pulley are small enough that we can safely ignore them. Thus the gravity force $F = m_2 g$ is the net force.

Starting with one of the kinematics equations:

$$x_f = x_o + v_o t + \frac{1}{2} a t^2 \tag{2}$$

Where the left side of the equation is the final position (x_f), as indicated by the subscript, and, the right side contains initial position (x_o), initial velocity (v_o), time (t), and acceleration (a).

In this experiment, we intend to control the initial, and final positions, as well as the initial velocity. We intend to measure the time, and solve for the acceleration. Therefore, we can rearrange equation (2) to be explicitly solved for acceleration as a function of (measured) time.

$$a_{exp} = \frac{2\Delta x}{t^2} \tag{3}$$

Equation (3) is our experimental equation, and, if you notice, we have introduced a symbol, Δ (Delta), which simply means "the change of", for example, $\Delta x = x_f - x_o$.

Activity 1.

1) Level the track by placing the bubble level near the middle and adjusting the heights of the different parts of the track by adjusting the feet under the track ends. Ensure the track is level at all points down the length of the track.

2) Weight the cart and string. Record your measurement on the data sheet.

3) Weight the paper clip and all of the masses to be used in this experiment. Record your measurement on the data sheet.

4) Thread the string from the end of the cart over the pulley and attach the paper clip (or rubber band) to the end. Attach 20g of mass to the end of the string and ensure that it can hang over the pulley while the cart is beyond the first gate.

5) By measuring from the front of one gate to the front of the next, confirm that the gates are 50cm apart. This particular step will greatly simplify your calculations.

Activity 2.

6) Set the timer to Time and mode to Two Gates. Add four 10g masses to the cart (so that 40g are on the cart, and 20g are hanging). Place the plastic picket fence on the cart so that one of the black vertical bars on the plastic fence intersects the gates (the red light on the photogate will light up when the bar intersects properly).

7) One person should be at the end of the track to act as the "cart catcher". Position the cart so that it as close to the first gate as possible. An assumption we made is that our initial velocity is zero. If the cart is moving significantly when it hits the first gate, our equation (3) no longer applies. To ensure you are as close to the gate as possible, move the cart forward until it triggers the gate (you will see a light turn red on the top of the gate). After the gate has been triggered, move the cart slightly backward until the light just turns off. Reset your timer by pressing the start/stop button two times (once to clear the run, and a second will reset it for the next run). Let go of the cart so that it begins to roll. The timer will measure the time that the cart takes to travel between the two gates. Repeat this procedure five times. Compute the average of your five measured times. Record these values on your data sheet.

Activity 3.

8) Repeat the measurements by moving one of the 10g masses from the cart to the mass hanger. Repeat this, moving 10g each time, until you have no masses left on the cart. Calculate the average transit time for each run of different falling mass. Calculate the square of this average time. Record both the total system mass and the transit distance. Make sure to record all data in Table 2 in the data sheet.

Activity 4.

9) Using the data from Table 2 on the data sheet, calculate the applied force, $F = m_2 * g$, where m_2 is the hanging mass. Do this for each of the different falling masses. Record these values in Table 3 on the data sheet. The units for the applied force will be $g*m/s^2$ or mN (milliNewtons).

10) Now calculate a_{exp} from Equation 3, where t^2 comes from Table 2 on the data sheet, and Δx is the transit distance, in meters (the distance the cart traveled between the photogates). Do this for each of the different falling masses. Record these values in Table 3 on the data sheet. The units for a_{exp} will be m/s^2.

Activity 5.

11) Using a spreadsheet, preferably Microsoft Excel, or other graphing software, prepare a graph of the applied force $F = m_2 * g$ versus a_{exp}. Make sure to label the axes and give your plot a title.

12) Using the trendline function, add a linear trendline to your plot. Make sure you turn on the trendline values to see the equation of the line.

13) The slope of the trendline will be an experimental value for the total system mass (in grams).

Activity 6.

14) Compare your experimental value for the total system mass to the one in Activity 3 on your data sheet by computing the percent difference. The percent difference is given by:

$$\text{percent difference} = \frac{\left|1^{st} measurement - 2^{nd} measurement\right|}{\left(\frac{1^{st} measurement + 2^{nd} measurement}{2}\right)} * 100 \tag{4}$$

Summary.

Answer the following questions and include with your data sheet:

How well does your experimental value for the total system mass compare to the one given in the generated data?

What factors could contribute to any differences between what you measured and what you expected?

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DATA SHEET

Activity 1.

Weight of the cart and string (in grams): ____________________

Weight of the paperclip and all masses (in grams): ____________________

Transit distance (in meters): ____________________

Activity 2.

Table 1: Record the cart transit times and compute the average.

Run 1	Run 2	Run 3	Run 4	Run 5	Average

Activity 3.

Table 2: Generate data table.

Hanging Mass (g)	Trial 1 (s)	Trial 2 (s)	Trial 3 (s)	Trial 4 (s)	Trial 5 (s)	Average (s)	Average^2 (s^2)

Total system mass (in grams): ____________________

Transit distance (in meters): ____________________

Activity 4.

Table 3: Prepare data to plot.

Applied Force (mN)	a_{exp} (m/s^2)

Activity 5.

Include a copy of your plot with this assignment. Make sure your plot is in the proper format. For example, are your axes labeled and show the proper units?

Activity 6.

Compare your experimental value for the total system mass to the one in Activity 3 above by computing the percent difference.

Percent Difference: ____

Answer the questions from the summary.