Newton's Second Law

Objective

We seek to understand the relationship between Force, Mass, and Acceleration. These quantities are all present in the basic form of Newtons Second Law, which we will be investigating. Furthermore, we will compare expected acceleration to experimental acceleration in cases where mass varies.

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 photogate "fence".

Background

Newton's second law is one of the most recognizable and applicable of the introductory physical laws. In plain language, it says two things: There is a measurable quantity called force, and that the sum of said forces is equal to the product of mass and acceleration.

$$\Sigma\vec{F} = m\vec{a} \tag{1}$$

Equation (1) restates what is written above, the sum (Σ) of forces ($\vec{F}$) is equal to the product of mass (m) and acceleration ($\vec{a}$). The arrow above F and a indicate that these are vector quantities, i.e. they have a direction. If there is a net force (a force greater than 0), the directions of the force and the resulting acceleration must be parallel to each other because, in addition to equal quantities on both sides of an equation, their direction must also be equivalent.

Short Derivations

We will be using 2 equations in this experiment. Equation (3) derives from one of the three kinematics equations:

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

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 first experimental equation, and, if you notice, we have introduced a symbol, Δ, which simply means "the change of", eg.$\Delta x = x_f - x_o$. The next equation comes from Newton's second law (equation 1), and requires a bit more rigor to get to the final form shown below in eq (4). Your instructor will most likely show the steps between (1) and (4).

$$a_{theo} = \frac{m_{hang} * g}{m_{hang} + m_{cart}} \tag{4}$$

In the above equation, the subscript, *theo*, refers to the theoretical acceleration, from newton's second law. Also shown above, m_{cart}, refers to the mass of the cart plus all of the masses on it. This equation uses only the masses of the system to predict the acceleration, while equation (3) uses measured data.

Experimental Outline

Step 1: Level the track by placing the bubble level near the middle and adjusting the heights of the different parts of the track by placing small paper shims under the sides and corners. Ensure the track is level at all points down the length of the track.

Step 2: Find the mass of everything together (cart, string, hanging implements, and all of the masse) by measuring it all on a scale together. Confirm that the masses are 10 grams or 20g each, depending on what they are supposed to be, and record each measured value. Thread the string over the pulley and attach the paper clip (or rubber band) to the end. Attach the 20 gram mass to the end of the string and ensure that it can hang over the pulley while the cart is beyond the first gate. 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.

Step 3: Set the timer to Time and mode to Two Gates. Add all four 10g masses to the cart (so that 40g are on the cart, and 20g are hanging). Place the Plexiglass fence on the cart so that one of the black vertical bars on the plexiglass fence intersects the gates (the red light on the photogate will alight when the bar intersects properly).

Step 4: 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, and place something "heavy" in front of the cart to prevent it from rolling through the first gate. 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). Remove the "heavy" object from in front of the cart quickly 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 for each mass total on the paper clip/rubber band. Use the average of your five measured times.

Step 4: Repeat the measurement by moving one of the 10 grams masses from the cart to the hanging masses. Continue to move 10 grams until you have no mass left on the cart.

Graphs and Diagrams

1a) Plot the acceleration of the system (equation (3)) versus the applied force due gravity on the mass added to the paper clip ($m * g$).

1b) Plot the theoretical system acceleration (equation (4)) verses the applied force ($m * g$) on the same graph.

2) Make a free body diagrams showing all the forces acting on the cart and the paper clip masses when the system is in motion.

Questions and Calculations

1) For each of your measurements, compute the theoretical and experimental acceleration of the system.

2) Compare the two accelerations. How different are they? do they get farther or closer as you changed the mass?

3) Compare the slope of the best-fit line through your data with the system mass. Be sure to include the mass of the cart.

4) We have neglected to include a certain force when using newton's second law to find our theoretical acceleration (eq. (4)), what was the force, and how would it affect (increase or decrease) the values of theoretical acceleration.