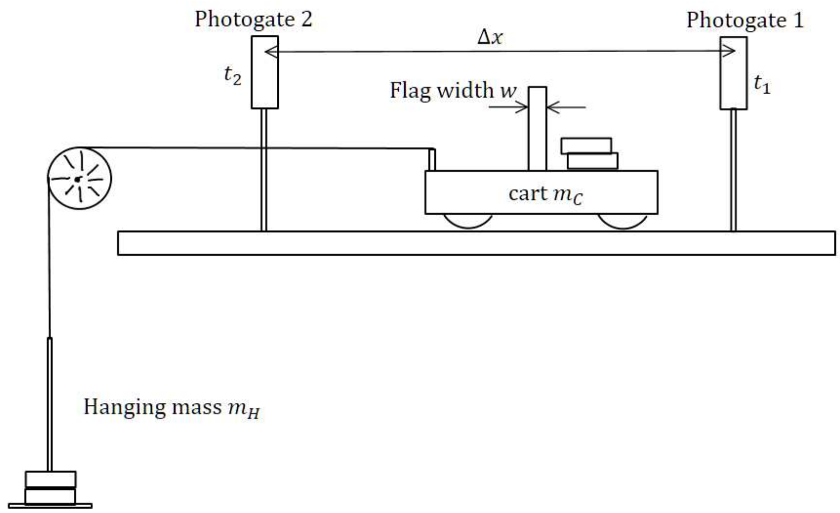
PH 201 Lab: Testing Newton's Second Law

Question: Does Newton's second law correctly describe the dynamics of a system with two objects? We'll investigate only one system, so this won't fully answer the question, but it's a start.

System: The diagram shows the system, consisting of a low-friction cart on a horizontal track attached by a light string over a low-friction pulley to a hanging mass. Two photogates are set up to find the speeds of the cart at two positions on the track. A scale is provided to measure the mass. Note the definitions of m_C and m_H:
m_C is the total mass of the cart and all the slotted masses it is carrying;
m_H is the total mass of the hanger and all the slotted masses it is carrying.



Designing the experiment: If Newton's second law is correct, then it can be applied (separately) to the cart and to the hanger. Draw the free-body diagrams as your instructor goes through it on the board.

Apply N2 to the cart: You will find that the equation for the horizontal motion of the cart is:

$$T = m_C a$$

where T is the tension in the string and a is the acceleration.

Apply N2 to the hanger: You will find the following equation:

$$m_H\, g - T = m_H\, a$$

In these two equations, the acceleration a, and the tension T are unknown. If we use the expression for T from the first equation, we can remove the T in the second, to get: $m_H\, g - m_C a = m_H\, a$. This can be rearranged in the following form:

$$a = \left(\frac{g}{m_C + m_H}\right) m_H$$

This is the equation we'll use to test Newton's second law.

Choosing variables and constants in our experiment: Recall that the equation of a straight line through the origin has the form $y = (constant)x$, where x and y are variables. Looking at our equation, a plot of the acceleration a versus the hanging mass m_H will give a straight line provided the part in parentheses is constant. That's easy to do: make sure the hanging mass is varied by **transferring** slotted masses from the cart so that $m_C + m_H$ remains constant.

To repeat: *All the masses in the experiment must remain within the accelerating system: they are either on the hanger, or on the cart. Transfer them from the one to the other, and don't put any back on the table.*

We'll measure the cart acceleration as we move more and more masses from the cart to the hanger. Then we'll plot the acceleration a versus the hanging mass m_H. If our hypothesis, Newton's second law, is correct, we will get data that follows the trend of a straight line.

The Scientific Method:

a. If we don't get a straight line (after checking if we did things right), we'll propose a new theory and start testing that
b. If we do get a straight line, we'll try a few more runs to continue verifying that our findings are consistent with Newton's second law. As a bonus, we'll measure the value of g from the slope.

Details for the experiment:
Your instructor will help get things set up. Pay attention to the instructions.

1. You will need to install the **Capstone** software on your computer.
2. You should also find the **.cap** file for this lab. After saving to your computer, double click on it.
3. The photogates should be connected to the Pasco 850 interface unit. Switch it on, and then connect the USB cable from the interface unit to your laptop.
4. Set the height of the photogate sensors so that the smallest flag, which has width $w = 2.50$ cm, is the one that breaks the beam. Look closely at each gate: one of the two tiny holes emits the beam.
5. To take data, hit the red 'Record' button.
6. Important: verify for yourself that everything is working. Check which times are for the first gate, and which for the second. Is the right flag blocking the beam? Is the software working? Do the times look about right? When you are sure you know what is going on, delete the test runs.
7. Make sure the track is horizontal. Check the wheels and pulley are running without noticeable friction.
8. Position the two gates so that the cart has rolled a few inches before the first gate is reached, and is able to move past the second gate before the hanger reaches the floor. Measure the distance Δx between the two gates. Make sure you don't bump the gates between runs.
9. Choose slotted masses so that you have about 10 different hanging masses covering the full range reasonably uniformly. For example, take five masses with values 10g, 20g, 20g, 50g, and 100g. Then it is possible to add masses of 10g, 30g, 50g, 70g, 90g, 110g, 130g, 150g, 170g, and 190 g to the hanger. (Remember, the rest of the masses need to be on the cart.)
10. For each run, make sure that the times recorded have three or more significant digits. For example, 0.0223 has three significant figures, while 0.022 only has two. Record all the digits measured by the timer; don't round them. The buttons at the top of the capstone panels adjust the number of digits.
11. The speed of the cart at each gate is found from the flag width and the time the beam is blocked: $v_1 = w/t_1$ and $v_2 = w/t_2$.
12. Find the acceleration of the cart by solving $(v_2)^2 = (v_1)^2 + 2a\,\Delta x$
13. You will need to measure the total mass $m_C + m_H$. To do this, place the cart on its side on the scale, together with the hanger and all the slotted masses used. (Or, measure the mass of the cart separately, and add the other masses to that.)
14. Make sure you follow the Excel guidelines when making the tables and graphs. (Did you make proper subscripts? Did you find the delta symbol Δ? Do you have too many significant digits?)
15. To calculate the value of g in your experiment, look at the equation we found and note that:
$$\text{slope} = \frac{g}{m_H + m_C}$$
Read the slope, with correct unit, from your trendline. Use the total mass you measured. Solve for g.

	$m_H + m_C$ (grams)
Expt 1	
Expt 2	

Δx (cm)	flag width w (cm)

Expt 1

m_H (g)	t_1 (sec)	t_2 (sec)	v_1 (cm/s)	v_2 (cm/s)	a (cm/s^2)

Expt 2

m_H (g)	t_1 (sec)	t_2 (sec)	v_1 (cm/s)	v_2 (cm/s)	a (cm/s^2)