Lab 4

Newton's Second Law - Part I

Continuing Objectives

1. Be able to identify sources of experimental uncertainty in a measurement.

3. Be able to write an experimental result (including correct number of significant digits, uncertainty, units).

4. Be able to make careful measurements to ensure reproducible results.

5. Know how to keep a clear and organized record, including an introduction (with purpose of lab and appropriate laws or equations), apparatus sketch, table of raw data and calculated quantities, and a good conclusion or summary.

7. Know how to make comparisons: are two measured quantities equal? Is a measured quantity statistically equivalent to a theoretical value?

8. Use a computer to collect and analyze data.

Lab-specific Objectives

1. Explore the relationship between force and acceleration qualitatively and quantitatively.

2. Use fan carts to explore the validity of the $\vec{F}_{\text{net}} = m\vec{a}$ equation (Newton's 2nd Law).

3. Explore and verify the vector nature of force and acceleration.

Introduction

Up until Newton's time, it was (incorrectly) believed that a continual force is needed to keep an object moving with constant velocity. Newton corrected this misconception by pointing out that:

1. constant velocity motion is maintained *without any applied forces* (Newton's First Law, also known as Galileo's Law).

2. a constant net applied force will result in a constant *acceleration*, i.e., changing velocity (Newton's Second Law).

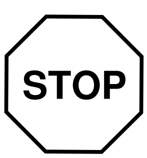
However, even today, most people still don't understand the connection between force and motion. Many people *still* believe (incorrectly!) that a constant force results in constant velocity.

To challenge this misconception, you will get a chance to **feel** and experience Newton's Laws for yourself in an exercise. You and your lab partner will go out to the hallway where one of you will pull an initially motionless cart with a constant force while the other sits on the cart holding a spring balance. The one pulling the cart will pull on the other end of the balance, keeping the reading on the balance at a constant value to assure a constant pulling force as your partner starts rolling along the hall.

After qualitatively studying the consequences of Newton's 2nd Law, you will then verify the law quantitatively using fan carts.

PRIOR to doing the first exercise, let's write some predictions about what we think may happen when one partner tries to pull a cart down the hallway with a **constant** force.

Write a sentence or two in your lab notebook stating what you believe your motion will be like during this experiment. Specifically, describe the motion you expect to have while pulling your partner or sitting on the cart being pulled. Once you and your lab partner have each made your prediction, share your thoughts with each other and note any interesting points from your discussion.



Show and discuss your predictions with your instructor or TA before continuing.

As there are a limited number of carts, the TA or instructor will let you know when a cart is available to test your predictions. For now, note your discussions with your lab partner and TA/instructor and continue the lab.

Procedure

Part I: Forces (qualitative)

NOTE: The TA or instructor will let you know when a cart is available for Part I. Skip to Part II while you wait.

1. Start with the rolling platform motionless at one end of the hall. Partner #1 should sit on the rolling platform, holding a bar connected to a force gauge. (They should have one foot on the floor initially to keep the platform motionless.) Take a look at the force gauge; you will notice that it uses a spring to measure the amount of force applied when you pull on either end. Test this out now.

2. Partner #2 should grab the string attached to the gauge and pull on it until there is a total reading of about 15 N. When Partner #2 is ready, Partner #1 should pick up their foot from the floor to allow the platform to move. From hereon, Partner #2 should keep an eye on the gauge, keeping the total force **constant** at about 15 N (or as close to constant as is possible) while Partner #1 and the platform roll along the hall. (Be careful not to clobber innocent bystanders in the hallway). It is essential that you do whatever is necessary to keep this force constant.

   As you are doing this, note what needs to be done to maintain a constant force. For the partner riding the cart, note how your motion feels as you travel the hallway pulled by a constant force.

3. When you run out of space, swap roles and repeat step 2, returning to the original location.

4. Return the cart to the starting position and go back to your lab bench. Write down a record of your observations. Look back at your predictions made at the beginning of today's lab and comment on anything noteworthy.

5. Discuss the exercise with your partner and compare what you experienced both pulling the cart and riding the cart. What needed to be done to maintain a constant pulling force? What did this feel like when riding the cart? How does what happened compare with your predictions earlier? What can you say about the common misconception that "constant force means constant velocity"?

Part II: Fan Cart Experiments

In this part of the lab, we will verify Newton's 2nd Law and explore the vector nature of force. On your lab bench, you'll find a ***low-friction*** (*not* frictionless!)

cart with a motorized fan. If you turn on the fan, the cart will experience a force that is assumed to be constant in time.

1. Place the cart at one end of the track and, with the fan aimed at 0°, turn it on and release the cart. Keep an eye on the cart as it moves toward the other end of the track, and **catch it *before* it crashes!**

   Checking Assumptions: Using only the items on your lab bench along with Logger *Pro* and the techniques that you used in the *Representing Motion* lab, devise and conduct an experiment that will enable you to determine if the net force acting on the fan cart is, in fact, constant as the cart moves down the track *under its own power*. The file you used in the *Representing Motion* lab, `211mot.cmbl`, is in the Lab 04 folder on the lab PC.

   STOP

   When you have completed your test, talk to your instructor or TA and using your data, convince them of your conclusion that the net force on the cart either does or does not remain constant.

2. **Without using Logger *Pro*** try the following: turn the fan on and give the cart a brief push on the track in a direction *opposite* to the force exerted by the fan. The cart should slow down, stop, and then move back toward the release point. In your lab notebook, make qualitative sketches of what you think plots of position, velocity, and acceleration (versus time) would look like for this process. Align your sketches vertically to be able to indicate same time with a vertical line.

   STOP

   Have your instructor or TA verify that you have made a prediction for these graphs (they won't tell you if you are correct), then use Logger *Pro* and the motion detector to verify or refute your prediction.

   Note: For the rest of this lab, you will use this method (i.e., pushing the cart initially against the fan force) to obtain your data using Logger *Pro*.

3. **Technique for measuring acceleration:** after obtaining graphs of position and velocity versus time for the fan cart using Logger *Pro*, you will use the following technique to determine the acceleration of the fan cart from *just* the force of the fan. You will then use this measurement to find the force on the fan cart from the fan.

   (a) After obtaining your Logger *Pro* data, use the electronic balance in the back of the room to measure the mass of the fan cart. Back at your lab

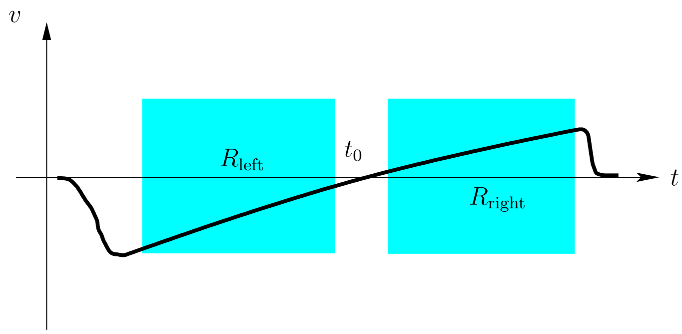


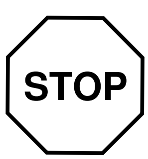
Figure 4.1: Graph of velocity vs. time for the fan cart using Logger *Pro*.

bench, open Excel and note the mass of the fan cart on a new spreadsheet (be careful to note the units!).

(b) On your graph of velocity vs. time in Logger *Pro*, the cart comes to rest momentarily at some time t_0 where the graph passes through the axis as indicated in Figure 4.1. You might notice that the slopes of the velocity graph are slightly different before t_0 and after t_0. Since these slopes represent the acceleration of the cart, this means that the acceleration is different for the two directions of travel of the cart.

(c) What might cause the acceleration of the cart to be different as it moves in two different directions? To help understand what forces the cart experiences before and after t_0, draw two Free Body Diagrams (FBDs), one for $t < t_0$ and one for $t > t_0$. Include all forces acting on the cart while it is in motion.

To obtain the most accurate measurement of the fan force, we will determine the acceleration before and after t_0, and then average the two results. We will call this average acceleration the "isolated acceleration," a_i. To find the force from the fan on the cart, we will multiply the isolated acceleration by the mass of the fan cart.



How can averaging the accelerations before t_0 and after t_0 help isolate and solve for the fan force? Show these FBDs to your TA/instructor and explain why finding the average acceleration (what we will call the "isolated acceleration") will allow you to determine the fan force.

(d) To determine the acceleration for times $t < t_0$, we will make one measurement of the slope of the curve in a time region as indicated by R_{left} in Figure (4.1). Click and drag your mouse over a region of time corresponding to R_{left} then select the `Linear Fit` button from the tool bar. The slope will then be displayed in a textbox on the graph. To show the uncertainty of the slope, double-click the textbox and check off `Show uncertainty`. Record this measured value of the acceleration and its uncertainty ($a_{\text{left}} \pm \Delta a_{\text{left}}$) in Excel.

(e) Determine a value for the acceleration in the region $t > t_0$ as indicated by R_{right} in Figure (4.1) by using the same procedure as in the previous step. Record this measured value of the acceleration and its uncertainty ($a_{\text{right}} \pm \Delta a_{\text{right}}$) in Excel.

(f) To determine the value of the isolated acceleration of the fan cart, take the average of the values a_{left} and a_{right}. The overall uncertainty in acceleration Δa is obtained in a manner similar to a previous lab:

$$\Delta a = \frac{1}{2}\sqrt{(\Delta a_{\text{left}})^2 + (\Delta a_{\text{right}})^2}. \tag{4.1}$$

4. Finally, to determine the fan force from this isolated acceleration, we will use the relationship between acceleration and force described by Newton's 2nd Law. Multiply a_i and its uncertainty by the mass of the fan cart measured earlier *(careful of units!)* to find the fan force and its uncertainty. Write these values down in your lab notebook in the correct format as described at the end of Lab 2 (also described in Appendix A.2.)

From now on, each time you are asked to determine an acceleration of the cart from a Logger *Pro* graph of velocity vs. time, you will follow this same exact procedure to find both the isolated acceleration and its uncertainty.

Part III: Forces Are Vectors

Now that we have developed a way to measure the fan force, we can explore more complex scenarios where the forces acting on an object are not necessarily acting along the x-axis.

On your fan cart, you will see that the fan can be turned up to 40° away from the starting point.

1. Discuss with your partner what will happen to the fan force if the fan is turned to a 30° angle. Will the force only be acting in the x-direction? How might this change of fan angle affect the motion of the fan cart? Comment in your notebook.

   Because force is a vector, the fan force will always act at a direction determined by the angle of the fan. This is true whether the fan is angled at 30° or at 0°.

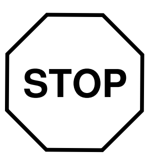
For this lab, we are only interested in forces contributing to acceleration in the x-direction (towards and away from the sensor), as this is what we can directly measure using Logger *Pro*.

2. How can we determine the fan force acting in the direction of motion? How would we calculate this when the fan angle is 0°? What about when the fan angle is 30°? Use variables such as the fan force when the fan angle is 0° (which is the magnitude of the fan force), F_{fan}, the fan angle θ, and the mass of the cart, m, to write an expression for the fan force in the direction of motion when the fan is pointed at an arbitrary angle.

3. We now have a way to calculate the expected fan force in the direction of motion for *any* fan angle acting on the fan cart. Since the mass of the cart is constant, Newton's 2nd Law allows us to determine the acceleration of the fan cart due to this fan force. Using our expression for the fan force in the direction of motion found in the previous step, how would the acceleration of the fan cart due to this force compare for a fan pointed at an angle of 0° to a fan pointed at 30°? *(Describe qualitatively for now.)*

   To verify our predictions, we can compare theoretical values for the isolated acceleration with the measured isolated acceleration of the fan cart for different fan angles using the technique we developed in the earlier section.

4. Before taking any data, make a prediction about what will happen to the position and velocity graphs if the fan is turned 30° compared to the original graphs when the fan was at 0°. Include sketches of the graphs for your predictions.

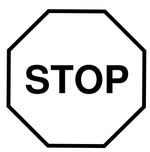


Show your predictions to your TA/instructor and explain your reasoning.

5. Let's check our predictions for the 30° case. First, we need to get data for the 0° case for comparison. Using Logger *Pro*, get the position and velocity vs. time graphs for the fan cart when the fan is set to 0°. Keep this run by using "`Store Latest Run`" under `Experiment`.

6. Collect another data set with the fan turned to 30°. It helps to start the fan cart from approximately the same position as the previous run for better comparisons. Print the graphs showing both the 0° and 30° fan angle data sets and tape these in your lab notebook. Compare your Logger *Pro* graphs to your earlier predictions. How has the motion changed?

7. Measure the acceleration for the cart due to the fan force in the same way you did in part II of today's lab. Record these data in Excel, separating the data for different fan angles accordingly. You should have an acceleration in the x-direction for a fan angle of 0° and for a fan angle of 30°.
8. Using Eq. (4.1), find the uncertainty on each acceleration.
9. Earlier we found that the acceleration due to the fan force acting at *any* angle can be determined if we know the fan force acting at 0°. Use your measurements and earlier expressions for fan force to calculate a theoretical value for the acceleration due to the fan force for a fan angled at 30°. Is this predicted value consistent with the measured value within 2 times the uncertainty?



Review your calculations and data with your TA/instructor and discuss whether or not the theoretical value of the acceleration is consistent with the measured value.

10. Write a summary of your findings for how force acts as a vector and how that can be used to determine the acceleration of a body along a particular axis.

Reflection

Please reflect on today's lab in your notebook.

Look back at today's lab-specific objectives (beginning of the lab).

1. What activities did you do today that helped practice or achieve these objectives?
2. How has your understanding of these topics changed through today's lab?