Lab 5

Newton's Second Law - Part II

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

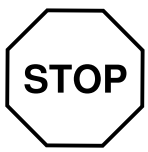
1. Explore the relationship between force and acceleration in a two-body system qualitatively and quantitatively.

2. Use mass carts and hanging weights to explore the validity of the $\vec{F}_{net} = m\vec{a}$ equation (Newton's 2nd Law) for a two-body system.

Introduction

In today's laboratory exercise, we will continue to investigate the consequences of Newton's Second Law: $\vec{F}_{net} = m\vec{a}$. This lab will extend our understanding gained in the previous Newton's 2nd Law lab by analyzing a "two-body" system.

Often in nature, two objects may be interacting with each other; the entire system's dynamics must be considered to make predictions about the motion of each part of the system. Such scenarios are known as "two-body" problems and require careful application of Newton's 2nd law to analyze. The two bodies may be connected through direct contact or via a string or rope as in today's lab. They may not even be visibly connected, but still considered a system as in the case of gravitational interactions. Understanding orbital motions of objects in space relies on the analysis of two-body problems; for example, scientists and engineers need to know how to correctly place a new satellite in a system so it orbits the Earth rather than escaping into space or crashing back to the planet.



With your lab partner, discuss some examples of two-body systems that you may have encountered in your everyday life. How do you think the forces acting on each object may be related? How about their accelerations? Note any predictions about two-body systems in your notebook and then discuss them with your instructor or TA.

Procedure

Part I: Two-body problem - Experiment

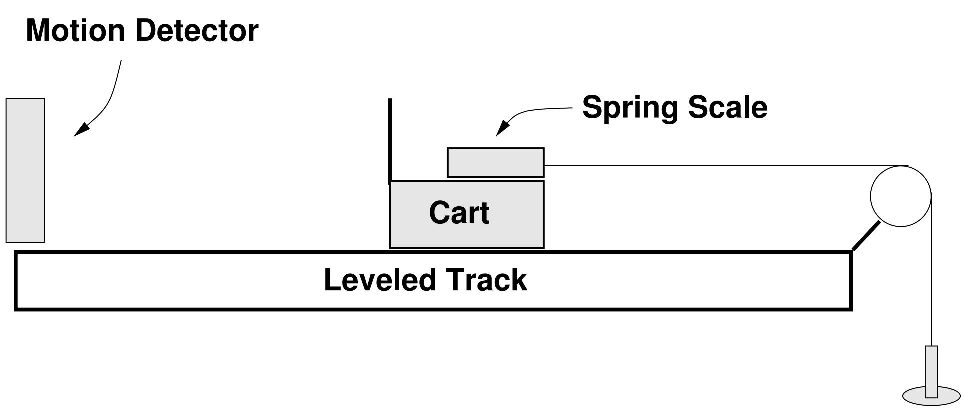


Figure 5.1: Apparatus for analyzing two-body motion

For experiments in this lab, the cart will be set up on the track as shown in Figure 5.1. The spring scale is attached to the cart, and the string is attached to the spring scale. With this configuration, the spring scale measures the tension in the string.

We will be using the same technique to measure the isolated acceleration of the cart on the track as we used in Lab 4: Newton's 2nd Law - Part I (giving the cart an initial push against the direction of motion and then letting it roll back). Consult your lab notebook for a reminder of how data was taken for that lab. The Logger *Pro* file from Lab 4 can be found in the folder: `Phys211_212 Lab/211Lab/Lab 05`.

STOP

Why do we need to give the cart an initial push toward the motion detector when taking our data? Look back at your procedure for Lab 4 and explain this technique's purpose to your TA or instructor.

1. Set up the apparatus as shown in Figure 5.1. Configure Logger *Pro* to measure the position and velocity as a function of time, and set the collection time to 10 seconds at 30 samples/sec. To do this: In the `Experiment` menu, choose the menu item `Data Collection...` and in the `Collection` tab change the "sampling rate" to 30 samples/sec and the "Duration" to 6 seconds.

2. Open the Excel template in the lab folder to keep track of acceleration and hanging mass data.

3. For each hanging mass value, you will obtain six good trial runs of position vs. time and velocity vs. time data. Start with 50 g of hanging mass (note: the hanger itself is 50 g) and position the hanger just above the floor such that the cart is far from the motion detector.

4. Start the Logger *Pro* motion detector and push the cart toward the detector (it will slow down, stop, and come back). **Catch the cart before it crashes.**

5. Determine the isolated acceleration from the Logger *Pro* graph of velocity vs. time as you did previously in Lab 4: *Newton's 2nd Law - Part I* by averaging the acceleration measurements before and after the velocity curve crosses the axis. IMPORTANT NOTE: If the Logger *Pro* data are choppy, try re-aligning the motion detector or move objects away from the track and try another run. You do NOT need to calculate the uncertainty from the uncertainty in the slope; we will handle it using multiple measurements based on our knowledge from Lab 3: *Statistical Uncertainties*.

   STOP

   Show your data for the first trial run of this hanging mass value as well as the calculated isolated acceleration to your instructor or TA before continuing.

6. Repeat steps 4 and 5 for trials of data with 150 g hanging mass.

Part II: Two-body systems – Theory

Now, let's apply Newton's second law to this problem and calculate theoretical values for the cart acceleration to compare with our experimental values.

1. Assuming the cart and spring scale to have a total mass m_{c} and the hanger/weights to have a mass m_{w}, use Newton's second law to derive an expression for the tension T in the string and the acceleration a for arbitrary m_{c} and m_{w} when the cart is accelerating. *Use the same step-by-step approach that you have been using in problem session.*

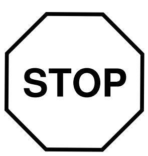
    (a) Draw a sketch of the system in your lab notebook.

    (b) Draw a free body diagram for each of the objects in the system (cart and hanger). Assume that there is no friction on the cart and no air resistance on the weight.

    (c) Write down Newton's second law, and identify coordinate systems for both objects next to your diagrams. (*Remember: It helps to define the x-axis along the direction of acceleration.*)

    (d) Apply Newton's second law for each free body diagram to sum all vector components in each direction.

    (e) Consider the two equations that contain the acceleration you measured. What quantities are the same between the two equations? There should be two. Use this fact to substitute one equation into the other. You should be able to solve both equations and get an expression for T that contains only m_{c}, m_{w}, and g, and then to get a similar equation for a.



Show your work to your instructor or TA before continuing.

We now have a way to solve for the acceleration of the cart given the mass of the cart and the hanging weight.

2. Measure the mass of the cart and spring scale using the electronic balance at the back of the lab room and record the value in your lab notebook.

3. For each of your different hanging mass variations, use the equation you came up with in step 1(e) to predict the acceleration of the cart. You should have two theoretical values for the cart acceleration, one for a hanging mass of 50 g and one for 150 g. We will compare these theoretical values to experimental values obtained in the lab to check Newton's 2nd Law for two-body systems.

Part III: Two-body system – Uncertainties

We now have theoretical and experimental values for the cart acceleration for both hanging masses of 50 g and 150 g. By now, the class data should be ready to use to find an uncertainty on our experimental values.

To find the uncertainty on our measurement for the average acceleration, we can use principles learned previously in Lab 3: *Statistical Uncertainties.*

1. Return to the collected data summarized in your Excel spreadsheet. You have made six careful measurements in each case. Use Excel to calculate your best estimate for the acceleration in each case. Be sure to determine the uncertainty associated to your best estimate.

2. Report your best value for the acceleration in each of the two cases, including the associated uncertainty.

STOP Show your work to your instructor or TA before continuing.

Now, we can compare our experimental results to the theoretical accelerations calculated earlier using Newton's 2nd law. If the two values are **consistent** with each other within 2 uncertainties, then Newton's 2nd Law can be said to be valid for a two-body system.

What does it mean to be **consistent**? A helpful way to visualize this is to draw a number line centered on your experimental result that stretches from $-2\Delta a$ to $+2\Delta a$ and seeing if the expected value lies within this range. If it does, then the data are consistent with the expected value within 2 uncertainties; if not, then the data are not consistent with the predicted value. Either way, whether the data are consistent or not with the expected value is an essential piece of information to include in your lab notebook.

3. Repeat the previous step for the 150 g histogram.

STOP Are your measured accelerations consistent with your predicted values? Discuss your conclusions with your instructor or TA.

4. Write a summary for this lab.

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 achieve these objectives?
2. How has your understanding of those topics changed through today's lab?
3. If you found some of your predicted accelerations were not in agreement with your measured values within 2$\times$ the uncertainty, consider what aspects of your measurements may be throwing your values off. Please don't say "human error", which is a non-specific, uninformative expression and does not really answer the question. Have you included all of the friction or drag forces, for example? If not, how would the forces that you left out of your theoretical predictions change your predicted acceleration, if you had included them? Would they increase or decrease your predicted acceleration? Would this tend to move your prediction closer to your experimental measurements or farther away?