**Newton’s Laws**

**(Two weeks, In-Person)**

# Notes:

1. This lab will be done in-person with your lab partner(s), in LD011.
2. You will prepare a short summary on what you did and submit to your TA on (or before) the due date. Summaries are not as detailed as lab reports. Your TA might (not always) provide feedback which you should incorporate into your later lab reports and/or lab summaries. The short summary should discuss some (not all) elements mentioned in the handout “Lab Overview”.
   1. When working in a group, turn in only one summary and make sure it lists all group members as authors.
   2. Summaries should be uploaded to Canvas in .pdf format by the deadline in the course calendar.
   3. Do not include raw spreadsheets in the Canvas submission or summary. You may want to use figures generated from the spreadsheet(s) in your summary.
3. Getting help:
   1. Your lab TA can answer questions during the lab or after the lab by email or at their office hour (listed in the syllabus).
   2. You can also ask advice from lab partner(s) and/or other students.

# Objectives of this lab:

For this lab, you will design and implement an experiment that measures the acceleration of a two-mass system and then compare your results with your calculations based on Newton’s laws. You will measure the acceleration based upon the kinematics. You should vary the mass-system (the cart mass and the “hanging mass”), and run the experiment multiple times.

These are things you will do:

1. You will use the motion detector to obtain data to extract the kinematical acceleration. Think of this as the “measured” acceleration since it is experimentally determined.
2. You will use the electronic balance to measure the masses (cart w/ any added masses, string, and “hanging mass” i.e, paperclips). This mass data will be used to uncover dynamical acceleration. Think of this as the “theoretical” acceleration.
3. You will record data and transfer it to Excel for analysis. Analysis will include, but not be limited to, the kinematical accelerations compared to the dynamical accelerations.
4. Identify errors that can occur in your experiment.
5. Minimize those errors.

# What you will learn:

Please review the learning goals for the semester in lab in the handout from the first week. In addition, this lab has several specific goals:

1. You will practice keeping lab notes in a paper notebook, computer file, or other format.
2. You will enhance the data analysis skills you learned previously, by applying them to real data.
3. You will learn to distinguish between two types of errors that occur in data: systematic errors and random errors.
4. You will enhance your understanding of how noise arises in data, and how to account for that noise when interpreting experimental results.
5. You will practice scientific communication skills by preparing graphs and writing a formal lab report.

## What goes in my lab notes, and what about my summary?

The purpose of lab notes is to enable you or a colleague to reconstruct what was done and why.

* They don’t have to be neat, in complete sentences, etc., but they do have to be useful.
* In a case like this, they should include things like what as the setup for measuring acceleration and what you did while recording data.
* Did you try different setups or take multiple data sets for same setup?
* If you store multiple files, record what filenames correspond to what conditions.

The purpose of a summary is to explain what you learned and how you learned it. This lab isn’t a formal written report, but you still need to give a sense of what you did and what you found. The sorts of things that belong here are

* A description of each step you did as part of Activity 1, Activity 2, and Activity 3.
* Any graphs to show to your results.
* Explain how you determined your results.
* Explain differences between calculated (theory) and the actual (measured) accelerations.
* Your conclusions about any relevant and useful information you were able to extract from data.
* An analysis of the errors of the in your experiment including an explanation of how calculated average acceleration, found the standard deviation, and determined the standard error.

# EQUIPMENT

For this lab, the following are available for use: dynamics cart, string, pulley w/ clamp, paper clips, set of standard masses, electronic balance, wooden stop-block, and motion detector.

**DOs & DON’Ts**

* ***Don’t*** break the equipment -- Make sure the cart/masses do not go too fast. Please do not drop the set of standardized masses.
* ***Do*** consult with your Lab TA about the various techniques you want to consider as you design your particular experiment.
* ***Don’t*** forget to record all the masses for each run (cart w/ any added masses, string, and “hanging mass” i.e, paperclips).
* ***Do*** use your imagination and have fun.

# Sample Set-Up:

For a sample set-up, attach the pulley at one of the edges of the table. Assemble the cart, string, and hanging mass as illustrated below:

# *Figure 1. Suggested setup for activities.*

Next, you will set-up a motion detector, positioned somewhere behind the cart, to measure the velocity of the cart versus time. You will need to spend some time on this, experimenting to find the best location.

You should practice, with multiple runs, starting the motion detector and then releasing the cart-system, to make sure that your set-up is able to accurately record the velocity of the cart as it accelerates. It needs to be able to record the velocity for the entire trip across the surface of the table.

# ACTIVITY 1 (1st week): Constant Cart Mass, Variable Hanging Mass

* Use a few standard masses and add them to the cart (e.g. two 250-gram masses). Don’t forget to record the total mass (cart with the added masses and string).
* Select a paperclip, this is your “hanging mass”. Don’t forget to record its mass.
* If the system does not move, select a heavier paperclip or add an additional one. Once the cart is able to move, you are ready for your runs. You should practice starting the motion detectors, releasing the cart, then stopping the motion detector.
* Make sure to do multiple runs for a given hanging mass. How many? You choose -- the more you do, the better your data and thus the experiment.
* Next, increase the hanging mass by adding another paperclip. Again, don’t forget to record the total hanging mass. Again, do multiple runs.
* Repeat, by adding another paperclip. How many times should you increase the paperclips? You choose -- the more you do, the better your data.
* Save your data for each run (cart mass, hanging mass, velocity vs time data) in Excel to make graphs, do analysis, etc.
* Using what you have learned in lecture about kinematics, free-body diagrams, and Newton’s laws, fully analyze this system. For example, one can easily obtain the “kinematical acceleration” from the data (see 1-D kinematics). In addition, from Newton’s laws, one can uncover the “dynamical acceleration” which is mostly a function of the masses and to a much lesser degree, axle friction (pulley and wheels), which we will ignore here.
* Think about how you want to analyze your data. Compare your kinematical “measured” acceleration to the dynamical “theoretical” acceleration. Recall, you have the data for multiple runs where you increased the hanging mass. Discuss and calculate the Percent Error. Explain.
* What other unknowns are buried in your data? String tension? String tension in the case of no-motion versus motion?

# ACTIVITY 2 (2nd week): Variable Cart Mass, Constant Hanging Mass

* Start with a 100-gram mass on the cart. Don’t forget to record the total mass [cart with the added mass(es) and string].
* Use five paperclips for your constant hanging mass. Don’t forget to measure the hanging mass.
* Make sure to do multiple runs for a given cart mass. How many? You choose -- the more you do, the better your data and thus the experiment.
* Next, increase the cart mass by adding a standard mass. Again, don’t forget to record the total cart mass. Again, do multiple runs.
* Repeat, by adding another standard mass to the cart. How many times should you do this? You choose.
* Save your data for each run (cart mass, hanging mass, velocity vs time data) in Excel to make graphs, do analysis, etc.
* Using what you have learned in lecture about kinematics, free-body diagrams, and Newton’s laws, fully analyze this system. For example, one can easily obtain the “kinematical acceleration” from the data (see 1-D kinematics). In addition, from Newton’s laws, one can uncover the “dynamical acceleration” which is mostly a function of the masses and to a much lesser degree, axle friction (pulley and wheels), which we will ignore here.
* Think about how you want to analyze your data. Compare your kinematical “measured” acceleration to the dynamical “theoretical” acceleration. Recall, you have the data for multiple runs where you increased the cart mass. Calculate and discuss the Percent Error.
* What other unknowns are buried in your data? String tension? String tension in the case of no-motion versus motion?

# ACTIVITY 3 (2nd week): Video Analysis for Variable Cart Mass

Basically repeat Activity 2 for a few runs, varying the cart mass, but now consider using the camera on your smartphone to video-record the experiment. First, using some masking-tape, mark off centimeters (don’t write on the lab tables) along the distance. Video-record it from overhead so that you can estimate distance moved as a function of time. Use Excel to store your data: distance moved by the cart as a function of time. Is the acceleration constant? Compute an average acceleration. How does this “video” average acceleration compare to your motion detector (kinematical) acceleration and how does it compare to the dynamical (theoretical) acceleration? Is the “video” average acceleration closer to the (theoretical) acceleration than when you used the motion detector? Discuss.