Newton's Second Law

Physics Topics

If necessary, review the following topics and relevant textbook sections from Serway / Jewett "Physics for Scientists and Engineers", 10th Ed.

- Kinematics under constant acceleration (Serway 2.7)
- Solving problems with Newton's Second Law (Serway 5.4, 5.7)

Introduction

In this experiment, we analyze the acceleration of a glider/cart which is pulled by a string. The string, in turn, passes over a pulley and is attached to a hanger to which mass can be added. The hanger accelerates vertically downward, causing the glider/cart to also accelerate. The glider/cart slides on an air-track; hence friction is negligible in this setup. Photogates are used to time the glider/cart as it moves along the airtrack; this timing information can be used to calculate the cart's acceleration.

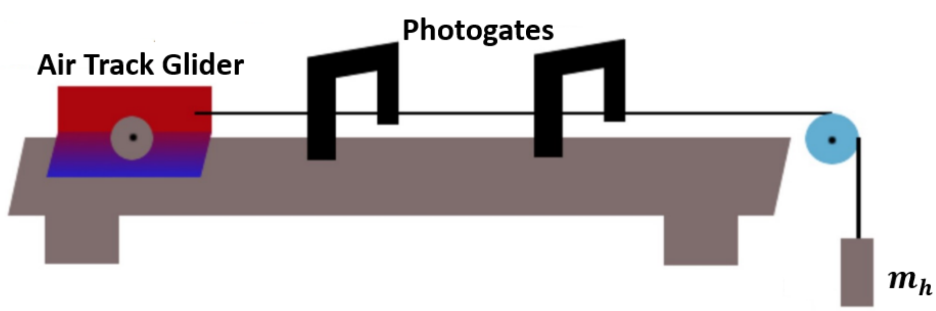

Figure 1: Apparatus (A), air-cushioned track and glider

There are two different setups for this experiment:

Apparatus (A)

- Air-cushioned track and glider
- Weights and hanger (increments of 5g)
- String
- Pulley and clamps
- Vernier Lab Pro
- Vernier Photogates (2)

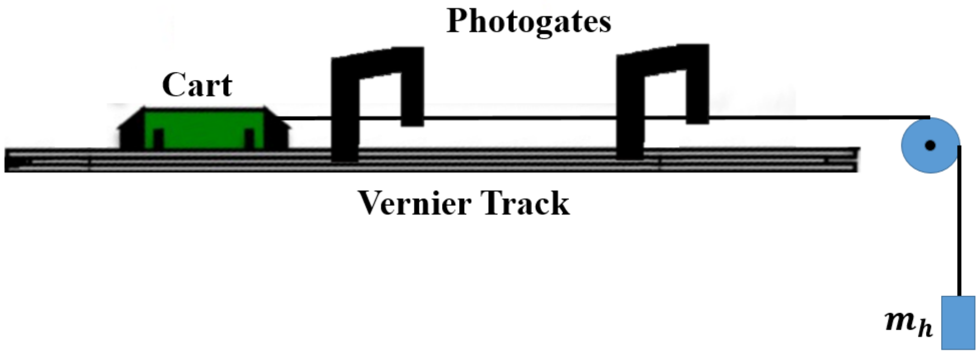

Figure 1: Apparatus (B), Vernier dynamics cart and track

Apparatus (B)

A cart with wheels running on a track.

- Vernier dynamics cart & track
- Photogate trigger (attach to top of cart)
- String
- Pulley and clamps
- Vernier Lab Pro
- Vernier Photogates (2)
- Weights and Hanger (increments of 50g)

Pre-Lab Questions

Please complete the following questions prior to coming to lab. They will help you prepare for both the lab and the pre-lab quiz (Found on D2L).

1.) Read through the entire lab writeup before beginning

2.) What is the **specific** goal of this lab? Exactly what question are you trying to answer? Be as specific as possible. ("To learn about topic X..." is **not** specific!)

3.) What **specific** measurements or observations will you make in order to answer this question?

4.) *Try to make this prediction* ***before*** *completing any other questions. It is not important that you get this prediction right. It is important that you think about it before beginning!* Suppose the glider/cart and the hanger had equal masses. Do you expect the magnitude of the acceleration of the glider/cart to be g, smaller than g, or bigger than g? Explain your reasoning in words.

5.) Analyze the glider/cart:

(a) Draw a sketch of the entire setup.

(b) Choose a coordinate system with the x-axis pointing right and the y-axis pointing up. Draw this on your sketch.

(c) Draw a free-body diagram for the glider/cart.

(d) What force **acting on the glider/cart** causes it to accelerate?

(e) Write Newton's Second Law in the x-direction for the cart. Denote the mass of the glider/cart (and any added weights) m_G, and its acceleration $\vec{a}_G$ (with components a_{Gx}, a_{Gy}.

6.) Analyze the hanging weight:

(a) Draw a free-body diagram for the hanging weight.

(b) Write Newton's Second Law in the y-direction for the hanging weight. Pay attention to your coordinate system! Denote the mass of the hanger (and any added weight) m_h, and its acceleration $\vec{a}_h$ (with components a_{hx}, a_{hy}.

7.) Since the string is taut and does not stretch, the acceleration components of the glider/cart and the hanger are related by $a_{Gx} = -a_{hy}$. (The minus sign must be there because of the coordinate system we chose! If the glider/cart accelerates in the +x direction ,the hanging weight accelerates in the -y direction). Use this fact, and the results of the previous questions to write an equation for the glider/cart's acceleration in terms of g, m_h and m_G.

8.) Looking at the figure in the introduction, suppose you knew velocity of the cart/glider at each photogate v_1 and v_2 and the distance between the photogates L. What equation could you use to determine the acceleration of the cart / glider? (Assume the acceleration is constant).

Procedure

1.) Measure and record the masses of all moving parts: the glider/cart, hanger and string, and all added weights.

2.) Measure and record the length of the plate on top of your glider/cart.

3.) Setup the Logger Pro software:

(a) Download the file NewtonSecondLawLab.cmbl from D2L

(b) Open the Vernier LoggerPro 3. Locate and open the file you downloaded.

(c) Within Logger Pro, select **Data** $\rightarrow$ **User Parameters**. Replace the default "PhotogateDistance1" & "PhotogateDistance2" values with your measured value for cart length.

4.) Set the two photogate timers over the track at a distance about 60 cm apart. Measure and record the distance L between the photogates. Keep this distance fixed for all trials.

5.) Connect the weight hanger to the glider/cart with a string placed over the pulley. The string should be long enough to ensure that the glider/cart clears the second photogate before the hanger hits the floor.

6.) Attach weights to the glider/cart and to the hanger. Start with 30g of weight on the glider (15g on each side), and 10g of weight on the hanger. Use the following initial masses depending on your apparatus:

- If you are using the air track setup, start with 30g of weight on the glider (15g on each side), and 10g of weight on the hanger.
- If you are using the cart setup, start with a 50g hanger and 150g of weight added to the cart.

7.) Choose a starting position for the glider/cart. Note and record this position. Place the glider/cart at this position and start all trials from this position.

8.) Hold the glider/cart and press the start collection ▶ button on the Logger Pro screen. Release the glider/cart.

9.) After the glider/cart has cleared the second photogate, the timers should read the length of time t_1 and t_2 the glider/cart took to pass under each gate (look under the IG1 and IG2 data columns). These are the time intervals from when the front of the glider (or front of the trigger on top of the cart) passes under the gate to when the back of the glider (or photogate trigger) passes under the gate. Record your data. Click **Experiment** → **Store Latest Run** to store the data.

10.) The program also will calculate the glider/cart's average velocity v_1 and v_2 as it passes through each photogate. Record this data also.

11.) Repeat the previous three steps twice more, recording the times for each trial.

Note: We recommend you save your data set of three trials for a given hanger mass - with filenames (for example) Trials-Mass15g, Trials-Mass25g, etc. Save each file to the desktop of the computer. You should save your data as both a .cmbl and a .csv file. Once all trials have been completed, upload them to the Lab 3 folder on D2L. <u>All data will be deleted from the computers at logoff.</u> Of course, the one sure way to make sure you don't lose your data is to record all data in your notebook.

12.) If you are using the air track setup, remove 10g of mass from the glider/cart and place it on the hanger. If you are using the cart, remove 50g of mass from the cart and place it on the hanger. Go back to step 7 and take three time trials with this new hanging mass. Record all data. Repeat this procedure until no more masses remain on the cart/glider.

Analysis

1.) For each hanger mass, the acceleration is constant. Use kinematics and the values of v_2 and v_1 to calculate the acceleration of the glider/cart. Record these results in a table.

2.) Plot a graph of acceleration (on the y-axis) vs. m_h (on the x-axis). Determine the slope of the line.

3.) Using the equation you derived in the pre-lab, what do you predict for the slope of the line when a is plotted vs m_h? [Hint: the combination $m_G + m_h$ is a constant since we only removed mass from the cart and added it to the hanger].

4.) Make a quantitative comparison between your measured slope and your expected slope. If there is a substantial disagreement between your predicted and measured slopes, you may need to double check your calculations and/or revisit the predicted equation you derived in the pre-lab.

Wrap Up

The following questions are designed to make sure that you understand the physics implications of the experiment and also to extend your knowledge of the physical concepts covered. Your report should answer these questions in the noted section in a seamless manner.

1.) [Discussion] After completing the lab, answer again the question posed in the pre-lab: If the glider/cart and the hanger had equal masses, will the magnitude of the acceleration of the glider/cart be g, less than g, or bigger than g? Explain why in words. If, after doing the lab, your answer changed, explain what you had wrong when you first made your prediction.

2.) [Theory] In the special case where m_h is <u>much</u> larger than m_G, what do you expect the acceleration of the system to be? Does your formula agree with this special case?

3.) [Theory] In the special case where m_h is <u>much</u> smaller than m_G, what do you expect the acceleration of the system to be? Does your formula agree with this special case?

4.) [Discussion] Throughout this lab, we neglected friction. If friction were present (it always is, to some degree), how would your results be affected? Would the slope of your measured line be larger or smaller than the predicted slope?

5.) [Discussion] Conceptually, what differences would you expect to see between the two apparatus (Air Track & Glider vs. Rail & Cart)? Comment on the need for different weights between the two systems. While in the lab: discuss your results with the group sitting across from you, are there any noticeable differences? Try to provide some explanation for these differences.

Report

Labs will be completed in groups, you will enroll in a group with your lab partner at the beginning of each lab session. Each group will submit a single report through the assignment section on D2L.

- **Introduction**
  - What is the experiment's objective?
- **Theory**
  - You may be able to show a derivation of the physics you're investigating, or you may want to reference a source that provides a description/equation representing the physics you're investigating.
  - You may want to provide graphs that illustrate or predict how you expect the system under study to behave.
- **Procedure**
  - Explain the systematic steps required to take any measurements.
- **Results and Calculations**
  - Tabulate your measurements in an organized manner.
  - Based on your procedure, you should know what your tables
  - Provide examples of any calculations.
- **Discussion and Conclusions**
  - Discuss the main observations and outcomes of your experiment.
  - Summarize any significant conclusions.
- **References**
- **(Appendices)**