LAKE FOREST COLLEGE
Department of Physics

PHYS 114 **Experiment 6: Newton's Laws on a System of Two Bodies** Fall 2024

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Date: 10/03/2023
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Preliminary Instructions
Create a folder for you and your lab partner. Save a copy of these instructions for each student to that folder. Include your name in the filename. Save one copy of the Excel template with both your and your partner's name included in the filename.

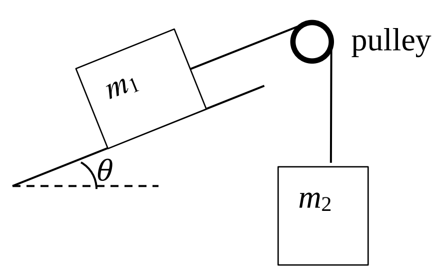
Experimental purpose of today's experiment
Measure the acceleration of a system of two connected bodies and compare to the predictions of Newtonian mechanics.

Pedagogical purpose of today's experiment
Study the application of Newton's second law to a system of two connected bodies.

Background
A few essential concepts come together in this laboratory:

- From our mathematical description of motion, we know that acceleration is the rate of change of velocity. The SI unit of acceleration is meters per second squared ($\mathrm{m/s^2}$).
- A force is a push or a pull on an object. From our study in the experiment "the vector nature of forces," we know that strings attached to weights can exert forces, and that these forces combine according to the rules of vector addition. When we speak of a net or resultant or total force on an object, we mean the vector sum of all of the forces on the object. The SI unit of force is the Newton (N).
- An object's mass is a measure of the degree of difficulty in changing that object's velocity; that is, its inertia. The greater an object's mass, the more force is required to accelerate it. The SI unit of mass is the kilogram (kg).
- It is found experimentally that the acceleration of an object varies inversely with the object's mass and directly with the net force on the object. This is Newton's Second Law of Motion, $\vec{F}_{\text{net}} = m\vec{a}$.

In this experiment, a car of mass m_1 slides on an air-track that may be inclined to the horizontal. A thread attached to this car passes over a pulley to a hanging mass m_2. The pulley has a built-in photogate that allows for a computer measurement of the change in position of the thread. Therefore, the one-dimensional position, velocity, and acceleration of the car can be determined as functions of time.



Procedure

Part I. Predictions

1. Draw a free-body diagram for the hanging mass (m_2). Apply Newton's second law to find an equation relating the tension in the string to the hanging mass and the vertical component of its acceleration.

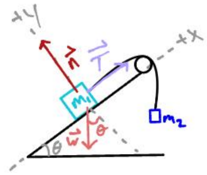
2. Draw a free-body diagram for the car (m_1). Find components of the forces parallel to the track and apply Newton's second law. Find an equation relating the tension in the string to the mass of the car, the angle of the incline, and the component of the acceleration of the car.

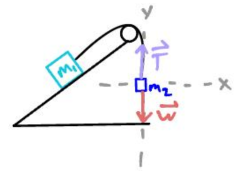
3. Since the car and hanging mass are connected by a string, their accelerations are related. They have the same magnitude but different directions. Write an equation relating the component of the car's acceleration parallel to the track to the vertical component of the acceleration of the hanging mass.

4. Solve these three equations to find the magnitude of the acceleration of the car and the hanging mass in terms of the two masses and the angle of incline of the track. For the conditions of this experiment, your answer should be:

$$a = \left(\frac{m_2 - m_1 \sin\theta}{m_1 + m_2} \right) g \qquad (1)$$

5. **Paste a picture of your derivation here**. **Include a caption.**





$$x: T = \frac{m_1}{m_1 g \sin\theta} = m_1 a_x \qquad x: 0 = 0$$

$$T = m_1 a_x + m_1 g \sin\theta$$

$$y: n = m_1 g \cos\theta = m_1 a_y = 0 \qquad y: T = m_2 g = m_2 a_y$$

$$n = m_1 g \cos\theta \qquad T = m_2 g - m_2 a$$

$$T = m_1 a + m_1 g \sin\theta \qquad T = m_2 g - m_2 a$$

$$m_1 a + m_1 g \sin\theta = m_2 g - m_2 a$$

$$m_1 a + m_2 a = m_2 g - m_1 g \sin\theta$$

$$a(m_1 + m_2) = m_2 g - m_1 g \sin\theta$$

$$a = \frac{g(m_2 - g\sin\theta)}{(m_1 + m_2)}$$

Figure 1. Free Body Diagrams and Equation Derivation. The tension force (T) is shown in purple and the weight force (w) is shown in pink. The normal force (n) is shown in red but only m_1 (light blue) has normal force as m_2 is suspended by a string. T is shared by m_1 and m_2 since we are assuming the string is an ideal string. This lets us set the values equal to each other and solve for acceleration (a).

Part II. Horizontal track ($\theta = 0$)

6. Add two extra weights to each side of the car. Your car should have identical attachments on both ends to keep it balanced. Use the Mettler balance to measure the total mass of the car.

7. Turn on the air-track and carefully level the track. When the track is properly leveled, a car released from rest should remain at rest or perform small oscillations.

8. Select a nominally 20 g hanging mass. Use the Mettler balance to measure its mass precisely.

9. Simplify Equation 1 for the special case of a horizontal track ($\theta = 0$). Use Excel to apply this equation and predict the magnitude of the acceleration in Part II of the spreadsheet. You do not need to find the uncertainty in the predicted acceleration. Assume it is negligible.

10. From the computer desktop, open the “Exp 6 pulley” Logger Pro file. When it asks for sensor confirmation, choose “connect.” **After collecting your data, save this file in your folder with a name for each trial. Do not modify the desktop file!**

11. Place the car on the track with the thread running parallel to the track. Use a ruler to assure that the thread remains parallel to the track throughout the range of motion. Check that the stop (made of silicone tubing) is not too close to the end of the track.

12. Pull the car away from the pulley until the hanging mass is close to the pulley clamp. Hold the car at rest and ensure that the hanging mass is not swinging. Open the Logger Pro data collection file “Exp 6 Two Bodies Force” and release the car from rest when the program is “waiting for data.”

13. Observe the velocity versus time graph. Select the portion of the graph showing the region of constant acceleration. Fit the graph to a straight line and record the slope (the magnitude of the acceleration) in Part II of the spreadsheet.

14. Use this method to measure the magnitude of acceleration 5 times. Save each of your Logger pro graphs to your folder. **Paste one of these graphs here. Include a caption.**

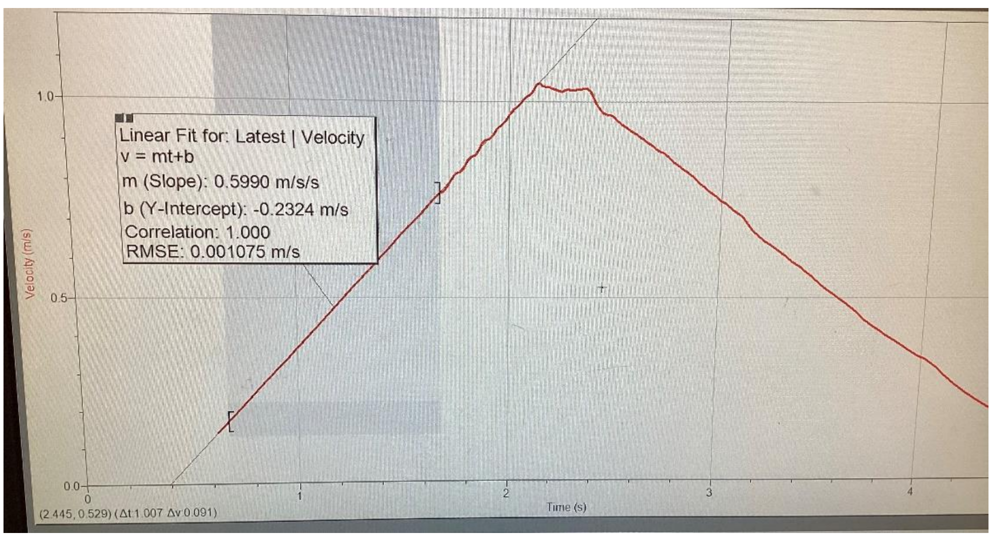


Figure 2 Velocity Starting at Rest Logger Pro Graph. In this trail m_1 starts at rest sitting on a level track and is pulled towards the pulley by the tension force of the falling 20g weight (m_2). The graph from Logger Pro shows the velocity of m_1. The slope of the velocity is the measured acceleration. This graph comes from the 2nd trail out of 5 with these conditions.

15. **Paste a picture of the apparatus here and label the important pieces. Include a list of equipment with their model #s where appropriate. Include a caption.**

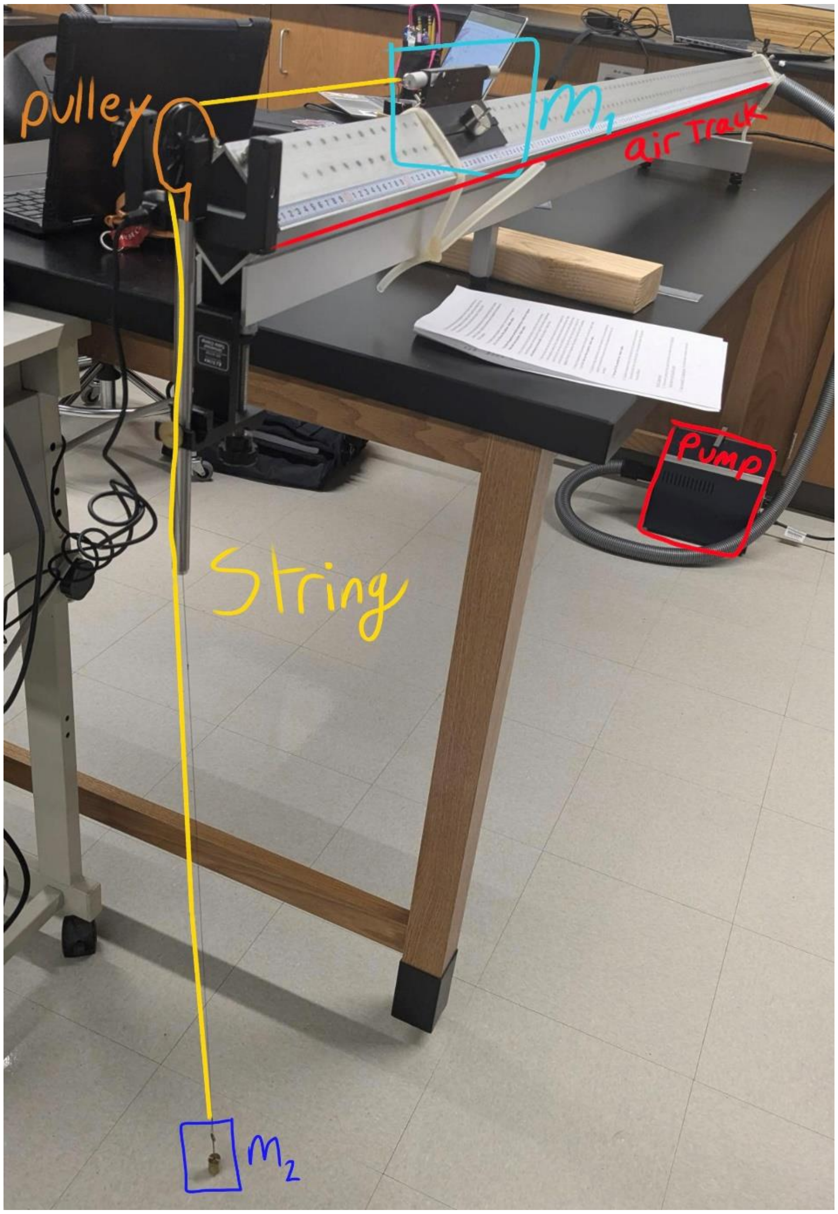


Figure 3 Two Bodies Apparatus. The Pasco Scientific air track outlined in red provides a simulated frictionless surface for m_1, outlined in light blue, to move across. The track was leveled to 0.0° with a Wixley Model WR365 digital angle gauge and level, not pictured. M_2, outlined in dark blue, hands from a string, highlighted in yellow, off the side of the lab bench. The pulley, outlined in orange, redirects the tension force from the string so it is shared by m_1 and m_2.

16. Now, you will start the car close to the pulley and give it an initial velocity away from the pulley. Assure that the hanging mass is not swinging, start the Logger Pro data collection, and **give the car a quick smooth push away from the pulley** when the program is "waiting for data."

17. Observe the velocity versus time curve. Note that the smart pulley only provides the magnitude of the velocity (the speed) as a function of time. It cannot determine in which direction the car moves. Select

a region of the velocity versus time curve where the car is moving away from the pulley (after leaving your hand) and slowing down. Fit that region of the velocity versus time graph to a straight line. The magnitude of the slope is the magnitude of the acceleration. Record this in Part II of the spreadsheet.

18. Perform five measurements of the acceleration with this method. Save each of the Logger Pro graphs to your folder. **Paste one of these graphs here**. **Include a caption.**

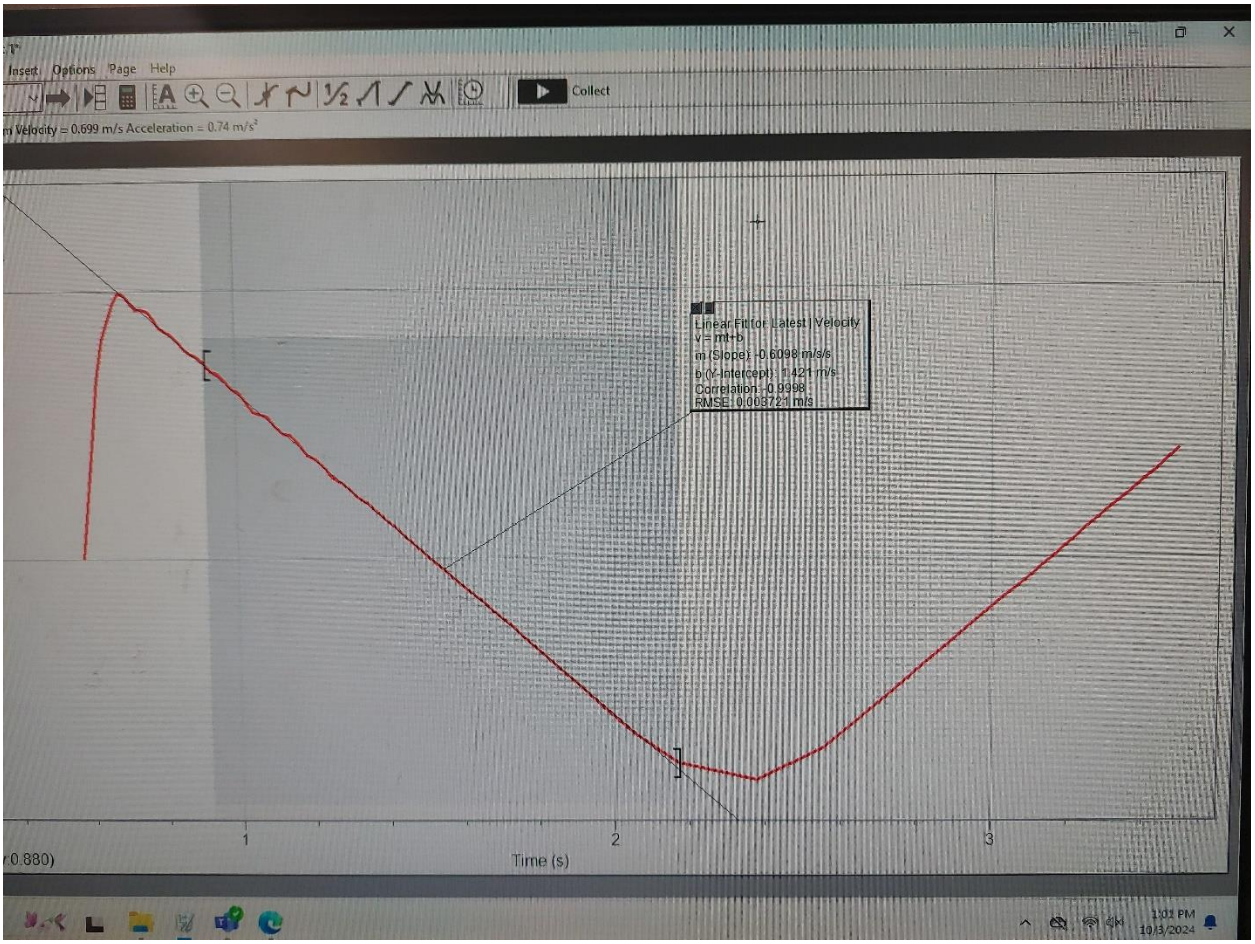


Figure 4. Push Start Velocity Logger Pro Graphs In this trial m_1 starts with initial velocity moving away from m_2 on a level track. It is then pulled back towards where it started and m_2. The acceleration was calculated from the magnitude of the slope of velocity as the m_1 moves away from m_2. This graph comes from the 1st of out 5 trials with these conditions.

19. Calculate the average, standard deviation, and relative uncertainty (%) of your ten accelerations and compare to your predicted value using our ratio test, with the standard deviation serving as the uncertainty.

20. **Paste part II of the spreadsheet here**. **Include a caption.**

Cart m_1 (kg)	Hanging mass m_2 (kg)	g (m/s^2)	predicted acceleration (m/s^2)
0.30048	0.02	9.803	0.6118

trial	initial condition	Measured magnitude of acceleration (m/s^2)
1	rest	0.5979
2	rest	0.599
3	rest	0.6003
4	rest	0.5994
5	rest	0.6017
6	initial velocity	0.6091
7	initial velocity	0.6156
8	initial velocity	0.6184
9	initial velocity	0.6118
10	initial velocity	0.6129

Average measured acceleration (m/s^2)	0.60661
St. Dev. of measured acceleration (m/s^2)	0.0078
Rel. Unc. of measured acceleraion	0.01
Ratio Test	0.66

Table 1. Flat Track Excel Spreadsheet. The predicted acceleration was calculated using a derived formula (Figure 1) with angle $\Theta = 0$. There was a total of 10 trials conducted while the track was flat. For the first 5 trials m_1 started at rest in the middle of the track and was pulled to the end. For the last 5 trials m_1 started at the end of the track and was pushed to the center. Only the magnitude of the acceleration was measured so all values are positive. The average acceleration comes from the excel command AVERAGE() and the standard deviation comes from the excel command ST.DEV.S().

21. Qualitatively examine the results of the trials where the car was released from rest to the trials where the car had an initial velocity away from the pulley. Is there a noticeable difference? Why might there be such a difference?

The acceleration was slightly higher when m_1 started with initial velocity.

Part III. Tipped track

22. Tip the track by placing the block under the foot of the air track closest to the pulley. Check that the thread does not touch the pulley clamp.

23. Select a nominally 50 g hanging mass. Use the Mettler balance to measure its mass precisely.

24. Use Wixey Digital Angle Gauge to measure the tilt angle of the track. Record the tilt angle and use Excel to apply Equation 1 and predict the acceleration of the car in Part III of the spreadsheet. (Don't forget that Excel functions use radians, not degrees.)

25. Measure the magnitude of the acceleration using the same procedure as above: five trials in which the car is released from rest, and five trials in which the car is pushed away from the pulley. Save all your Logger Pro graphs. Record all the accelerations in Part III of the spreadsheet. **Paste one example of each type of graph here. Include a caption.**

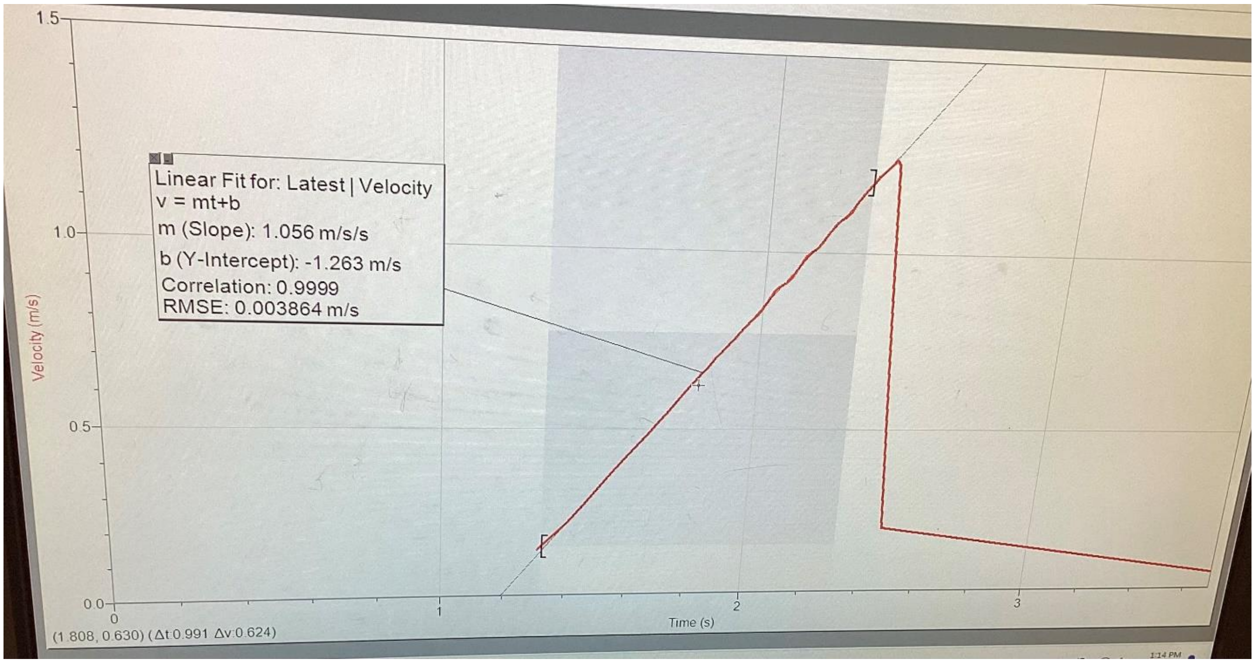


Figure 5. Tipped Track Velocity Graph. In this trial m_1 starts at rest on a track with a tilt of 2.0° away from m_2. The tension for pulls m_1 towards m_2 with a velocity shown above. The slope of the velocity represents the acceleration. This graph comes from the 2nd out of 5 trials with these conditions.

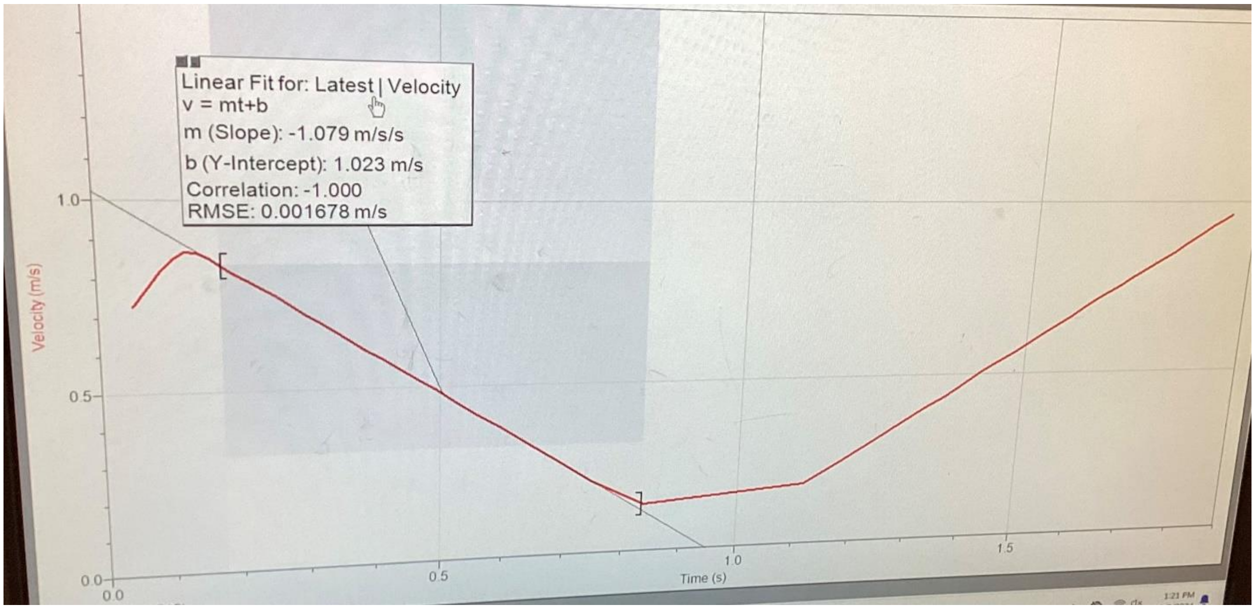


Figure 6. Tipped Track Acceleration Graph. In this trial m_1 gently pushed away from m_2 along a track with a 2.0° tilt. M_1 starts moving back towards m_2 and the end of the track when the acceleration changes direction. The acceleration was calculated from the magnitude of the slope of velocity as the m_1 moves away from m_2. This graph comes from the 3rd out of 5 trials with these conditions.

26. Calculate the average, standard deviation, and relative uncertainty (%) of your ten accelerations and compare your measured acceleration to the predicted value using our ratio test. In this case the uncertainty in the angle creates a significant uncertainty in the prediction. Use 0.03 m/s^2 as the uncertainty in the predicted acceleration.

27. **Paste part III of the spreadsheet here. Include a caption.**

Cart m_1 (kg)	Hanging mass m_2 (kg)	g (m/s^2)	angle q (degrees)	predicted acceleration (m/s^2)	Uncertainty in predicted acceleration (m/s^2)
0.30048	0.05	9.803	2.0	1.105	0.03

trial	initial condition	Measured acceleration (m/s^2)
1	rest	1.055
2	rest	1.056
3	rest	1.02
4	rest	1.057
5	rest	1.057
6	initial velocity	1.146
7	initial velocity	1.076
8	initial velocity	1.079
9	initial velocity	1.092
10	initial velocity	1.077

Average measured acceleration (m/s^2)	1.0715
St. Dev. of measured acceleration (m/s^2)	0.033
Rel. Unc. of measured acceleration	0.03
Ratio Test	1.03

Table 2 Tipped Track Excel Spreadsheet. The predicted acceleration was calculated from a derived formula (Figure 1) where ϴ = 2.0° (the tilt of the track). The track was tilted so the end of the track with the pulley (Figure 3) was above the other end of the track. The first 5 trials were conducted with m_1 starting from rest. The last 5 trails were conducted with m_1 starting with initial velocity.

Write a brief analysis of both parts here. Are there any potential systematic effects? How might these effects affect your measured accelerations?

There may be variation from how much initial velocity is applied to m_1. This would increase the measured acceleration. All the measured accelerations with the same conditions were very similar. All the measured accelerations with a level track and 20g weight were similar and all measured accelerations with a 2.0° tilted track and 50g weight were similar.

28. **Write a brief conclusion for all parts here.** Was there agreement between your measured and predicted accelerations?

This experiment works because the tension force on m_1 and m_2 are the same because of the ideal string and pulley. No matter what is pulling on what the acceleration will always be the same as long as the weights of the objects do not change. The average measured acceleration agrees with the calculated predicted acceleration via ratio test for both experiments.

29. Adjust the formatting (pagination, margins, size of figures, etc…) of this report to make it easy to read. Save this report as a PDF document. Upload it to the course Moodle page.

30. Clean up your lab station. Put the equipment back where you found it. Remove any temporary files from the computer desktop. Make sure that you logout of Moodle and your email. Ensure that the laptop is plugged in.

31. Check with the lab instructor to make sure that they received your submission before you leave.