Name_______________________________ Date_________________

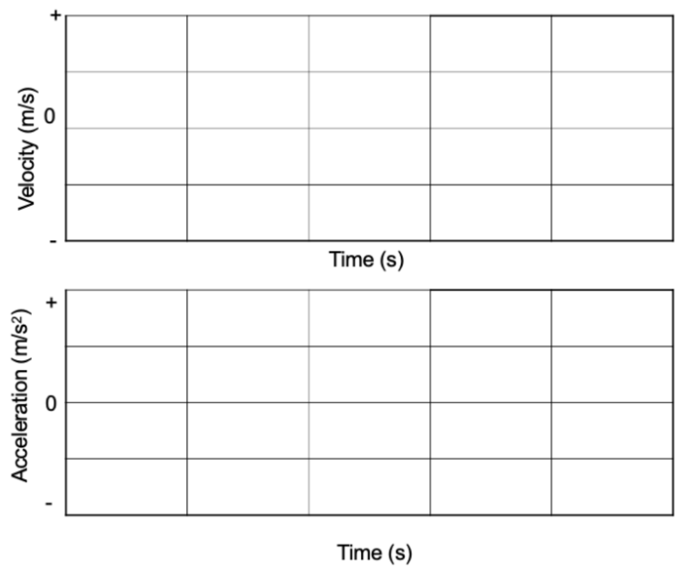
PRE-LAB PREPARATION SHEET FOR LAB 5: GRAVITATIONAL FORCE

(*Due at the beginning of Lab 5*)

Directions:

Read over Lab 5 and then answer the following questions about the procedures.

1. Sketch the graphs for Prediction 1-3 (line) and Prediction 1-4 (dotted line) on the graphs below. If the two predictions look different, explain why in words next to the graphs.



2. What is your answer to Prediction 3-2? What do you think will happen to the tension in the string when the system is free to move?

3. What is your answer to Prediction 3-4? Explain your answer as a limiting case (i.e., cart mass >>> hanging mass, or cart mass → ∞)

Name________________________Date_____________Partners____________________

LAB 5:
GRAVITATIONAL FORCE

OBJECTIVES

- To examine the magnitude of the acceleration of a falling object under the influence of the gravitational force near the Earth's surface.
- To examine the motion of an object along an inclined ramp under the influence of the gravitational force.
- To explore the relationship and difference between weight and mass.
- To explore the normal force as a reaction force.

OVERVIEW

During the early part of the seventeenth century, Galileo experimentally examined the concept of acceleration. One of his goals was to learn about freely falling objects. Unfortunately, his timing devices weren't precise enough to allow him to study free-fall directly. Instead, he decided to limit the acceleration by using fluids, pendulums, and inclined planes. In this experiment, you will have tools capable of studying acceleration for an object in free-fall, but you will also see how the acceleration of a rolling cart depends on the incline angle.

From a lifetime of experience, we as humans have a strong sense of intuition for gravity. In the same way that Newton built off of Galileo's work, the following experiments aim to build upon that intuition with graphical trends and mathematical models.

MATERIALS

- Graphical Analysis application
- Lab Quest Mini Base
- Low friction track
- Basketball
- Motion Detector
- Protective wire basket for motion detector
- Meter stick
- Go Direct Sensor Cart

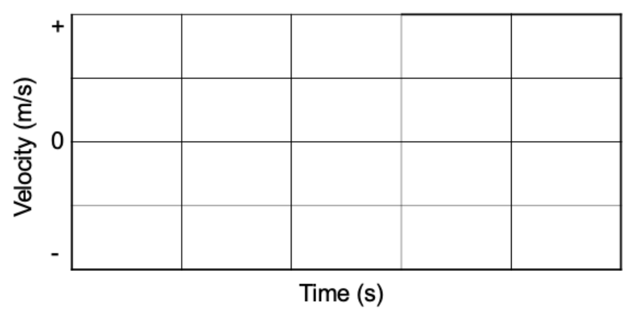
INVESTIGATION 1: MOTION AND GRAVITY

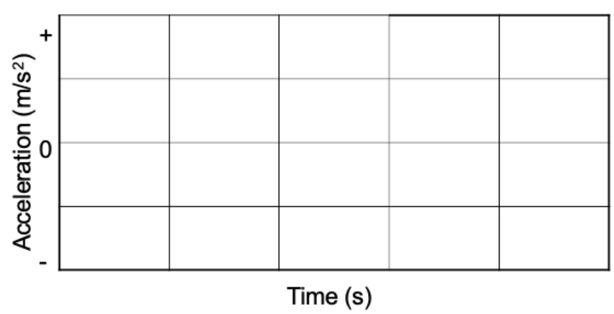
In Lab 3 you made a prediction for the sign of the acceleration for a ball that had been thrown in the air: while it was rising, when it reached its highest point, and while it was on its way back down. In this investigation, we will use a motion detector to collect velocity and acceleration data for a ball thrown straight upward. Analysis of the graphs of this motion will allow us to test those predictions.

While the ball is in the air (and air resistance has a negligible effect), we say that the ball is in free-fall. This refers to the fact that the ball is not in contact with other objects and is free from forces – except for one. Near the surface of the earth, an object's vertical motion will be affected by a constant force due to gravity.

Activity 1-1: Motion of a Falling Ball

Prediction 1-1: Consider the motion of a dropped ball as it travels in free-fall. Sketch your prediction for the velocity vs. time and acceleration vs. time graphs. Next to each graph, describe in words what this graph tells you about the motion. Assume that upward is the positive y direction.





Test your predictions. It may be difficult to aim the ball directly above the motion detector, you may have to repeat the experiment multiple times. Be careful when you identify which parts of your graph are related to the ball moving in free-fall.

1. Launch Graphical Analysis. Click to open Data Collection Settings in the lower left-hand corner of the screen. Change End Collection to 2 sec, and increase the collection rate to 30 samples/sec. If two graphs are not displayed, click View, ⊞, and choose 2 Graphs.

2. Place the motion detector on the floor and protect it by placing a wire basket over it.

Question 1-2: Have we observed something in a previous lab that moved in a similar way? If so, what?

Question 1-3: While the ball is in free-fall, what is the sign of the acceleration? How can you tell from the acceleration vs. time graph? How can you tell from the velocity vs. time graph?

Activity 1-2: Calculating Gravitational Acceleration

In Lab 2, you found two ways to calculate a value for the average acceleration. For the first method, we calculated the average acceleration by hand based on the displacement over a dozen time steps; here, you will examine the graph of the acceleration vs. time and find the mean. The second method is to find the slope of the velocity vs. time graph.

1. Examine the graph of acceleration vs. time. Select the data that corresponds to when the ball is in free-fall, then click on Graph Tools, , and choose View Statistics. Record the average (mean) acceleration in the table below.

2. For the second method, examine the graph of velocity vs. time. Select the data in the region that corresponds to when the ball is in free-fall. Click on Graph Tools, , and choose Apply Curve Fit. Select Linear as the curve fit and click Apply. Record the parameters of the best fit line in the table below.

Curve Fit Parameters	**A (m/s^2)**	**B (m/s)**
Velocity (v = At +B)		
Average Acceleration		

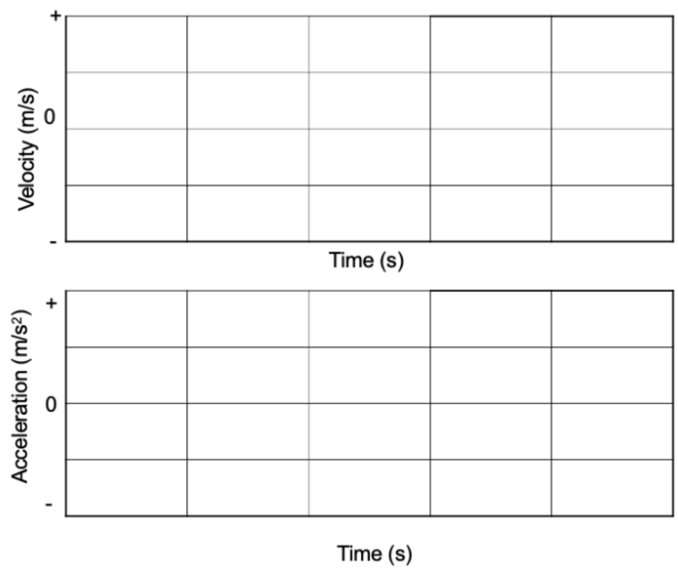
Question 1-4: Do these two calculated acceleration values agree with each other? Should they?

Question 1-5: What is the meaning of the second parameter, B, in the best fit line from the velocity graph? How would the graph change if that value was different?

Activity 1-3: Motion of a Ball Rising and Falling

Prediction 1-2: When a juggler tosses a ball straight upward, the ball slows down until it reaches the top of its path. The ball then speeds up on its way back down. A graph of its velocity vs. time would show these changes. Describe in words what the velocity vs. time and acceleration vs. time graphs would look like.

Prediction 1-3: Sketch your predictions of the velocity vs. time and acceleration vs. time graphs for the entire motion of the ball from the moment it leaves your hand until just before it returns to your hand. Assume that the positive direction is upward. **Mark on both graphs where the ball reaches maximum height**



1. Test your prediction by collecting data. During data collection you will toss the ball straight upward above the motion detector and let it fall back toward the motion detector. It may require some practice to collect clean data. To achieve the best results, keep in mind the following tips:

    - Hold the ball approximately 0.5 m directly above the motion detector when you start data collection.
    - The ball only needs to rise about 0.5 m to provide enough data.
    - Use two hands and pull your hands away from the ball after it starts moving so they aren't picked up by the motion detector.

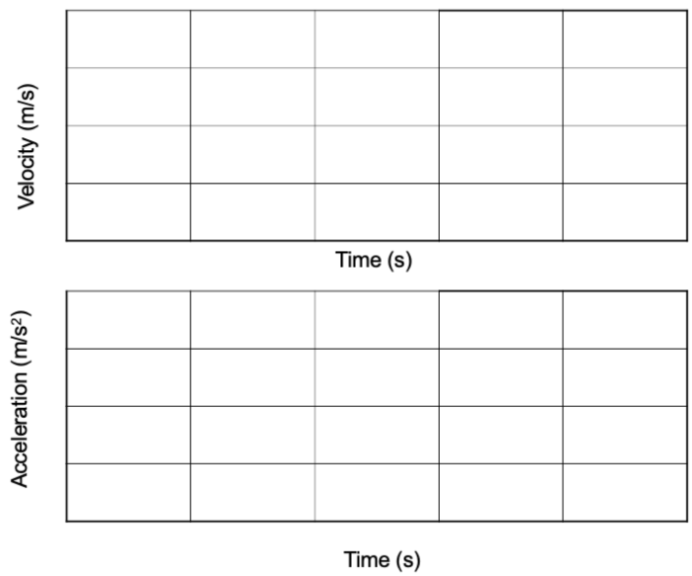
2. When you are ready to collect data, click Collect and toss the ball as you have practiced. You may need to extend the Data Collection time.

3. Sketch or print out your resulting acceleration and velocity graph. If you sketch your results, **write in values for your axes.**

Question 1-7: Were your predictions for the velocity and acceleration graphs correct? How were they correct? If not, what was different?

Question 1-8: On the velocity vs. time graph, mark when the ball's velocity was zero. How can you tell from the velocity vs. time graph that the ball's velocity is zero at that point?

Question 1-9: On the acceleration vs. time graph, mark when the ball's velocity was zero. Can you tell based on the acceleration vs. time graph alone? If not, what additional information did you use?



Question 1-10: Looking at the acceleration vs. time graph **alone**, what kind of motion(s) could be caused by this acceleration? List any.

Extension 1-4: Air Resistance

The ball used in this lab is large enough and light enough that air resistance may affect the acceleration in a small way. To observe a more significant effect from air resistance, repeat the ball dropping experiment three times, this time using a large, flat piece of Styrofoam.

Prediction 1-4: What differences, if any, do you expect to see in the velocity vs. time and acceleration vs time graphs for the falling Styrofoam?

1. Collect data while the Styrofoam is being dropped above the detector.

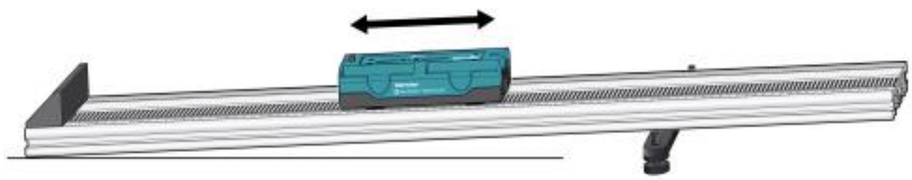
2. Average the three accelerations for the ball heading up, and for the ball heading down.

Question E1-1: How does the average acceleration for the rising motion compare to the falling motion? Explain any differences.

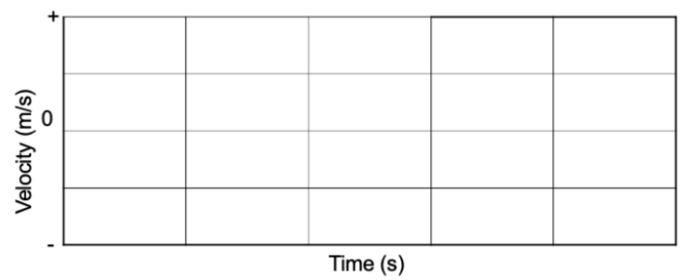
Question E1-2: Did your velocity vs. time graphs for the beach ball look different from your velocity vs. time graphs for the basketball? Should they? Explain.

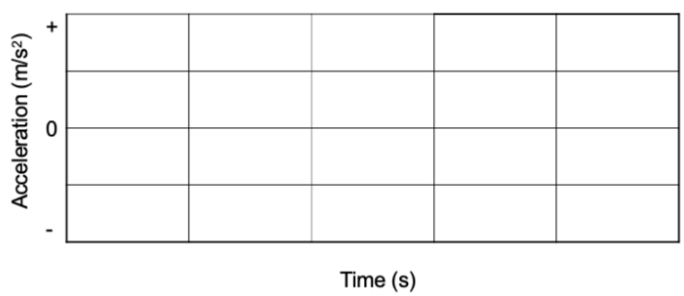
Activity 1-5: Motion Along an Inclined Ramp

An object moving along an inclined plane is another example of an object's motion being affected by the gravitational force.



Prediction 1-4: Consider the change in motion that a cart will undergo as it rolls up and down an incline. Make sketches of your predictions for the velocity vs. time graph and the acceleration vs. time graphs. Describe in words next to the graphs what each graph tells you about the motion.





Prediction 1-5: How will these graphs be similar to the ones from dropping a ball in Activity 1-1? How will they be different?

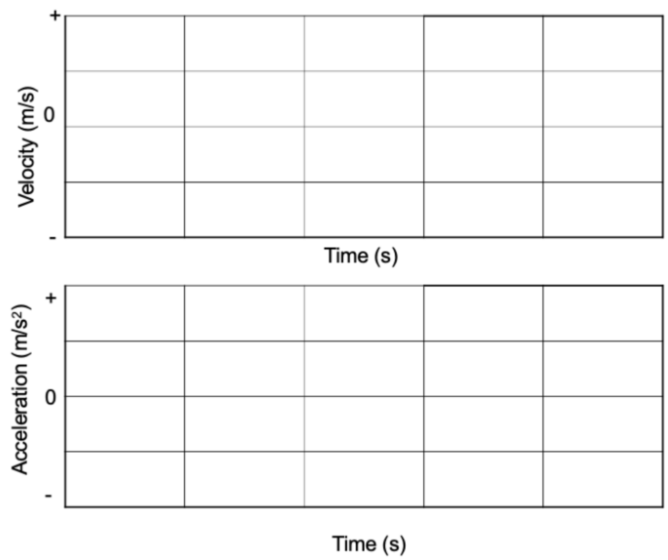
1. Launch Graphical Analysis. Connect the Sensor Cart to your computer. Open Data Collection Settings in the lower left-hand corner of the screen and change End Collection to 5 sec.

2. Use a riser to lift one end of the track so that it makes an angle of about 10-15˚ with the table. Place the cart on the track near the adjustable end stop. Point the **+x** arrow toward the top of the ramp. Click collect to start data collection. Wait about a second, then briefly push the cart up the incline, letting it roll freely up near to the top, and then back down. Catch the cart as it nears the end stop.

3. Examine the position vs. time graph. Repeat Step 2 if your position vs. time graph

does not show an area of smoothly changing position. Check with your instructor if you are not sure whether you need to repeat data collection.

4. Sketch the graphs on the axes below or **print** and attach them to this lab.



5. Indicate on both graphs the instant when the cart was at its highest point on the track.

6. Select the data in the region of the acceleration vs. time graph that represents when the cart was rolling freely. Click Graph Tools, , and choose View Statistics. Record the average (mean) acceleration.

Average (mean) acceleration: ________m/s^2

Question 1-11: Did the graphs look the way you predicted? Explain.

Question 1-12: How does the magnitude of this acceleration compare to the magnitude of the acceleration found in Activity 1-1 and Activity 1-3?

Question 1-13: What force caused the motion of the cart to change after you removed your hand? How is this similar to Activity 1-3? How is it different?

INVESTIGATION 2: A STUDY OF GRAVITY

Newton's second law states that an object will accelerate if a net force is applied to it: $\Sigma \vec{F} = m\vec{a}$. Usually, we can identify the sources of the net force based on physical contact, but in the case of the force of gravity, sometimes referred to as weight, there does not have to be contact. Work through these exercises to highlight some important ideas about the gravitational force.

MATERIALS

- A piece of foam
- A light rubber or golf ball
- A heavier metal ball

Activity 2-1: Discovering Gravity

The mass of an object is a measurement of how much "stuff" (protons, neutrons, electrons) it comprises. Mass is related to inertia, the property of how difficult it is to change the motion of an object. According to Newton's Second Law, the more mass an object has, the more force is required to achieve the same acceleration.

Question 2-1: Shake the light ball in one hand and the heavy ball in the other hand. Based on the experience, which ball has a greater inertia? What does that tell you about its mass?

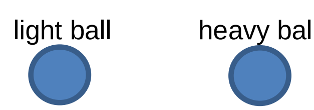
Prediction 2-1: If you held the balls at an equal height and dropped them at the same time, which ball do you think would hit the ground first?
Circle one: (Light Ball / Heavy Ball / Both Tie)

Now run the experiment, dropping the balls from the same initial height at the same time.

Question 2-2: Which ball hit the ground first? Does this result make sense? What does this tell us about the respective accelerations of the two balls?

Question 2-3: Based on what you have observed about the masses of the balls and their respective accelerations, (1) what can you say about the gravitational forces pulling down on them? (2) Does the more massive ball experience a gravitational force that is stronger, weaker, or the same in magnitude to the gravitational force on the less massive ball?

Draw a force diagram for each ball during free-fall:



Activity 2-2: The Gravitational and Normal Force

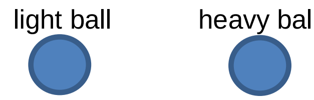
Place the two balls on the Styrofoam pad. You should see the pad deform as the balls compress the material.

Question 2-4: Which ball causes a greater compression in the Styrofoam?

Question 2-5: Now place the balls on the table. How is their interaction with the hard surface of the table similar, and how is it different? Are the balls compressing the table?

Question 2-6: While the two balls sit on the table, their acceleration is zero. Does this mean that there are no forces acting on the balls? Explain your answer.

Draw a force diagram for each ball as they sit on the table:



Question 2-7: The normal force is a passive response force from the table pushing up on the balls. What object causes the gravitational force pulling down on the balls?

Activity 2-3: Mass and Weight

Question 2-8: What is the difference between weight and mass?

Question 2-9: When an astronaut goes to the moon, does their weight change? Does their mass change?

Question 2-10: Can the metal ball from the previous activity experience weightlessness? Can it experience masslessness? In both cases, how?

INVESTIGATION 3: TENSION AND GRAVITY AND ∑F = MA

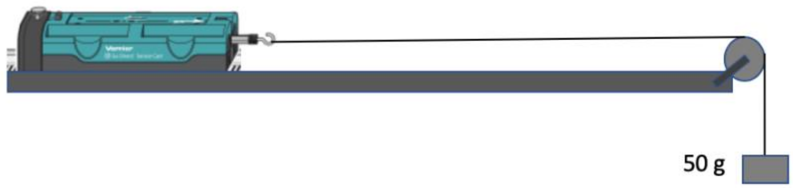
You have learned that when the sum of the forces acting on an object is zero, its velocity does not change. However, when a net force acts on an object, it accelerates. In this experiment, you will determine the relationship between the force of gravity and the force of tension acting on a hanging mass to explain the acceleration of the hanging mass-cart system.

MATERIALS

- Graphical Analysis application
- Low friction track
- Go Direct Sensor Cart
- Pulley and pulley bracket
- Lightweight mass hanger (50 g)

Activity 3-1: Tension in modified Atwood's Machine

Connect a weight to a sensor cart by running a string over a pulley, as shown. This setup is called a modified Atwood's machine. When the weight is allowed to fall, observe the motion of the cart. A force sensor mounted on the cart will enable you to measure the force acting on the cart when it is moving. First, make some predictions.



Prediction 3-1: If you hold the cart stationary, what will the magnitude of the tension be? How do you know?

Prediction 3-2: If we release the cart and the mass starts to fall, what will happen to the tension in the string? Will it increase, decrease, or remain the same? Explain your prediction.

1. Launch Graphical Analysis. Make sure the cart is on and connect the sensor cart to your computer. Open Data Collection Settings in the lower left-hand corner of the screen. Change End Collection to 5 s, then click Done. The two graphs being displayed should be force vs. time and velocity vs. time.

2. Zero the Force Sensor on the Force and Acceleration Sensor **while the string is unattached** before collecting data.

3. Click Collect to start data collection. Wait for one second to collect force and velocity data while you are holding the cart stationary, then release the cart. Catch the cart before it hits the pulley.

Question 3-1: What happened to the magnitude of the tension when the cart was released? Explain why.

Activity 3-2: How Cart Mass Affects Tension

Prediction 3-3: Suppose that you increase the mass of the cart but keep the hanging mass the same as in Activity 3-1. How will the tension in the string compare to the original setup while the system is **stationary**? Will it be the same, stronger, or weaker?

Prediction 3-4: If you increase the mass of the cart but keep the hanging mass the same as in Activity 3-1, how will the tension in the string compare to the original setup while the system is **moving**? Will the tension be the same as in the original setup, stronger, or weaker?

1. Highlight the portion of the force vs. time graph for which you want to find the mean value. Click on Graph Tools, , for the force vs. time graph and choose View Statistics. Read the mean value of tension and record it in the table for the "Light Cart" scenario.

	Tension when stationary (N)	Tension when accelerating (N)
Light Cart		
Heavy Cart		

2. Add 500 grams to your cart and repeat the experiment from Activity 3-1. Remember to hold the cart stationary for one second of data collection before releasing it.

3. **Print** the tension graphs for both cart mass scenarios shown on the same set of axes.

4. Find the average tension in the string while the heavy cart system was stationary and while it was moving using the same method as in Step 1. Fill in the spaces in the above table for the "Heavy Cart" row.

Question 3-2: What happened to the tension in the heavy cart system when it started to move? How did it compare to the tension in the light cart system when it started to move?

Question 3-3: Is this result consistent with your prediction? If not, what additional factors did you have to consider?

Question 3-4: Does the mass of the cart affect the tension in the string while the system is stationary? When the system is stationary, what determines the tension in the string?

Question 3-5: Does the mass of the cart affect the tension when the system is in motion?

Question 3-6: How does the mass of the cart affect the tension in the string while the system is in motion? As the cart mass increases, how does the tension change for an accelerating system?

Name____________________Date____________Partners___________________

HOMEWORK FOR LAB 5: GRAVITATIONAL FORCE

1. Using your observations from Activity 2-1 and Newton's Second Law, explain why gravitational acceleration has a constant value, regardless of mass, for all objects near the surface of the earth. Cite specific observations from the activity. (i.e. if acceleration is constant but mass is changing, what else must be changing?)

2. In Activity 1-3, you threw a ball into the air and observed its motion as it rose and fell. How do the velocity and acceleration change in time for the ball as it rises and falls? Describe both the magnitude and direction of the ball.

3. Consider the modified Atwood's machine in Activity 3-1: a cart of mass $\mathbf{m_1}$ on a frictionless track is connected to a hanging mass $\mathbf{m_2}$ by a string running over a pulley. For each of the following four scenarios,

- Draw a free body diagram for $\mathbf{m_1}$ and another for $\mathbf{m_2}$
- Apply Newton's Second Law to each mass
- Calculate the tension in the string. **SHOW YOUR WORK.**

a) A cart of mass $m_1 = 0.275$ kg, a hanging mass $m_2 = 0.05$ kg. The cart is held stationary.

b) A cart of mass $m_1 = 0.275$ kg, a hanging mass $m_2 = 0.05$ kg. The cart is not held, the system is free to move.

c) A cart of mass $m_1 = 0.775$ kg, a hanging mass $m_2 = 0.05$ kg. The cart is held stationary.

d) A cart of mass $m_1 = 0.775$ kg, a hanging mass $m_2 = 0.05$ kg. The cart is not held, the system is free to move.

4. How do your calculated values compare to the results of Activity 3-2?

5. The tension in the string in scenarios **3b** and **3d** are calculated using the same general equation using m_1 and m_2.

a) Write down the general equation for tension from **3b** and **3d.**

b) For the limiting case $m_1 >> m_2$, what happens to the strength of the tension in the string? What value does the acceleration approach?

c) What happens to the tension in the string for the limiting case $m_1 << m_2$? What value does the acceleration approach?