## *Physics I – Lab #4*

# Part A - Newton's Second Law

How does a cart change its motion when you push and pull on it? You might think that the harder you push on a cart, the faster it goes. Is the cart's velocity related to the force you apply? Or does the force just *change* the velocity? Also, what does the mass of the cart have to do with how the motion changes? We know that it takes a much harder push to get a heavy cart moving than a lighter one.

A Force Sensor and an Accelerometer will let you measure the force on a cart simultaneously with the cart's acceleration. The total mass of the cart is easy to vary by adding masses. Using these tools, you can determine how the net force on the cart, its mass, and its acceleration are related. This relationship is Newton's second law of motion.

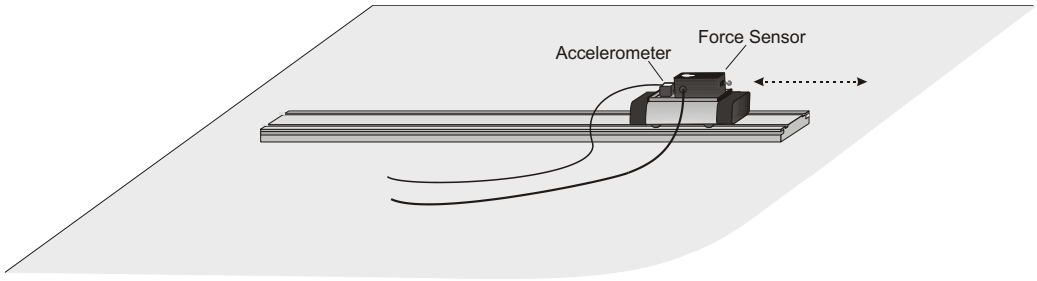



*Figure 1*

**OBJECTIVES**

- Collect force and acceleration data for a cart as it is moved back and forth.
- Compare force *vs*. time and acceleration *vs*. time graphs.
- Analyze a graph of force *vs*. acceleration.
- Determine the relationship between force, mass, and acceleration.

**PRELIMINARY QUESTIONS**

1. When you push on an object, how does the magnitude of the force affect its motion? If you push harder, is the change in motion smaller or larger? Is this a direct or inverse relationship?
2. Assume that you have a bowling ball and a baseball, each suspended from a different rope. If you hit each of these balls with a full swing of a baseball bat, which ball will change its motion by the greater amount?
3. In the absence of friction and other forces, if you exert a force, *F*, on a mass, *m*, the mass will accelerate. If you exert the same force on a mass of 2*m*, would you expect the resulting acceleration to be twice as large or half as large? Is this a direct or inverse relationship?

**PROCEDURE**

1. Connect a Dual-Range Force Sensor to Channel 1 on the Vernier computer interface. Connect the Low-g Accelerometer to Channel 2 on the interface.
2. Open the file "09 Newtons Second Law" from the *Physics with Vernier* folder.
3. Attach the Force Sensor to a dynamics cart so you can apply a horizontal force to the hook, directed along the sensitive axis of your particular Force Sensor. Next, attach the Accelerometer so the arrow is horizontal and parallel to the direction that the cart will roll. Orient the arrow so that if you *pull* on the Force Sensor the cart will

move in the direction of the arrow. Find the mass of the cart with the Force Sensor and Accelerometer attached. Record the mass in the data table.

4. Place the cart on a level surface. Make sure the cart is not moving and click Zero. Check to make sure both sensors are highlighted and click OK.

**Trial I**

5. You are now ready to collect force and acceleration data. Grasp the Force Sensor hook. Click Collect and take several seconds to move the cart back and forth on the table. Vary the motion so that both small and large forces are applied. Make sure that your hand is only touching the hook on the Force Sensor and not the Force Sensor or cart body.

6. Note the shape of the force *vs.* time and acceleration *vs.* time graphs. Click the Examine button, , and move the mouse across the force *vs.* time graph. When the force is maximum, is the acceleration maximum or minimum? To turn off Examine mode, click on the Examine button, .

7. The graph of force *vs.* acceleration should appear to be a straight line. To fit a straight line to the data, click on the graph, then click the Linear Fit button, . Record the equation for the regression line in the data table.

8. Print copies of each graph.

**Trial 2**

9. Attach a 0.500 kg mass to the cart. Record the mass of the cart, sensors, and additional mass in the data table.

10. Repeat Steps 5–8.

## DATA TABLE

### Trial I

| Mass of cart with sensors (kg) | |
|---|---|

| Regression line for force *vs.* acceleration data |
|---|
| |

### Trial 2

| Mass of cart with sensors and additional mass (kg) | |
|---|---|

| Regression line for force *vs.* acceleration data |
|---|
| |

**ANALYSIS**

1. Compare the graphs of force *vs.* time and acceleration *vs.* time for a particular trial. How are they different? How are they the same?

2. Are the net force on an object and the acceleration of the object directly proportional? Explain, using experimental data to support your answer.

3. What are the units of the slope of the force *vs.* acceleration graph? Simplify the units of the slope to fundamental units (m, kg, s).

4. For each trial compare the slope of the regression line to the mass being accelerated. What does the slope represent?

5. Write a general equation that relates all three variables: force, mass, and acceleration.

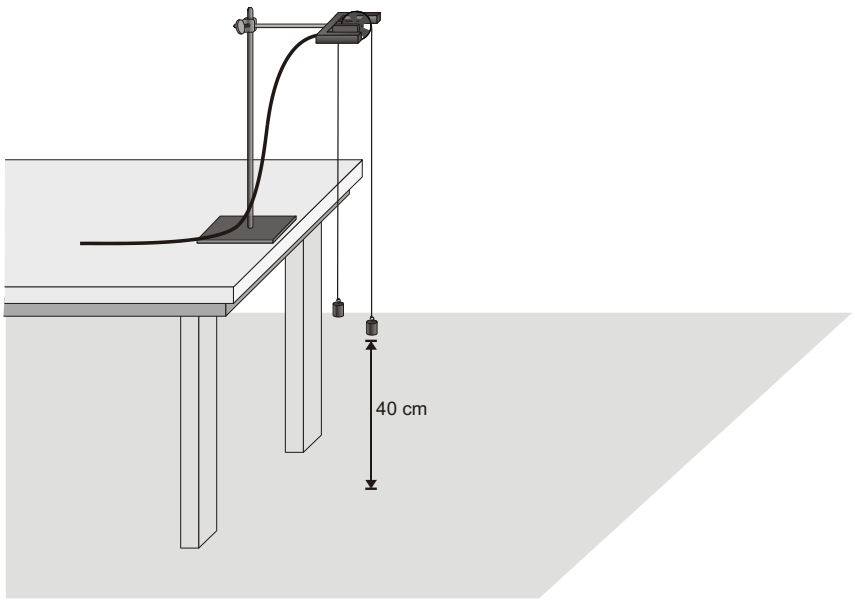
**EXTRA STUFF**

1. Use this apparatus as a way to measure mass. Place an unknown mass on the cart. Measure the acceleration for a known force and determine the mass of the unknown. Compare your answer with the actual mass of the cart, as measured using a balance.

# Part B - Atwood's Machine

A classic experiment in physics is the *Atwood's machine*: Two masses on either side of a pulley connected by a light string. When released, the heavier mass will accelerate downward while the lighter one accelerates upward at the same rate. The acceleration depends on the difference in the two masses as well as the total mass.

In this lab, you will determine the relationship between the two factors which influence the acceleration of an Atwood's machine using a Photogate for measuring acceleration.




## PRELIMINARY QUESTIONS

1. If two equal masses are suspended from either end of a string passing over a light pulley (an Atwood's machine), what kind of motion do you expect to occur? Why?

2. Why do the two masses have the same acceleration?

3. Draw a free-body diagram of the left side mass. Draw another of the right side mass. Include all forces acting on each mass.

## PROCEDURE

**Part I Constant Total Mass:** For this part of the experiment you will keep the total mass used constant, but move weights from one side to the other, changing the difference in mass.

1. Set up the Atwood's machine apparatus as shown in Figure 2. Be sure the heavier mass can move at least 40 cm before striking the floor.

2. Connect the Photogate with Super Pulley to DIG/SONIC 1 of the interface.

3. Open the file "10 Atwoods Machine" in the *Physics with Vernier* folder. A graph of velocity *vs.* time will be displayed.

4. Arrange a collection of masses on each side of the pulley so that there are equal masses on each side (i.e. $m_2 = m_1$). What is the acceleration of this combination? Record your values for mass and acceleration in the data table.

5. Move part of the mass from $m_2$ to $m_1$. Record the new masses in the data table. It may be easiest to move mass in 10 gram increments.

6. Position $m_1$ as high up as it can go. Click ▸ Collect to begin data collection. Steady the masses so they are not swinging. Wait one second and release the masses. Catch the falling mass before it strikes the floor or the other mass strikes the pulley.

7. Click the Examine button and select the region of the graph where the velocity was increasing at a steady rate. Click the Linear Fit button to fit the line $y = mt + b$ to the data. Record the slope, which is the acceleration, in the data table.

8. Continue to move masses from $m_2$ to $m_1$, changing the difference between the masses, but keeping the total constant. Repeat Steps 6–7 for each mass combination. Repeat this step until you get at least five different combinations.

**Part II Constant Mass Difference:** For this part of the experiment you will keep the difference in mass between the two sides of the Atwood's machine constant. You will add mass to each side in equal amounts in each step.

9. Place a mass on each pulley so that there is about 20 more grams on $m_1$ than $m_2$.

10. Repeat Steps 6–7 to collect data and determine the acceleration.

11. Add mass in 20 g increments to both sides, keeping a constant difference of 20 grams. Record the resulting mass for each combination in the data table. Repeat Steps 6–7 for each combination. Repeat the procedure until you get at least five different combinations.

| Part I: Total Mass Constant | | | | | |
|---|---|---|---|---|---|
| Trial | $m_1$ (g) | $m_2$ (g) | Acceleration ($m/s^2$) | $\Delta m$ (g) | $m_T$ (g) |
| 1 | | | | | |
| 2 | | | | | |
| 3 | | | | | |
| 4 | | | | | |
| 5 | | | | | |

| Part II: The Mass Difference Constant | | | | | |
|---|---|---|---|---|---|
| Trial | $m_1$ (g) | $m_2$ (g) | Acceleration ($m/s^2$) | $\Delta m$ (g) | $m_T$ (g) |
| 1 | | | | | |
| 2 | | | | | |
| 3 | | | | | |
| 4 | | | | | |
| 5 | | | | | |

## ANALYSIS

1. For each trial, calculate the *difference* between $m_1$ and $m_2$. Enter the result in the column labeled $\Delta m$.

2. For each trial, calculate the *total mass* in grams. Enter the result in the column labeled $m_T$.

3. Disconnect all sensors and choose New from the File menu. Plot a graph of acceleration *vs.* $\Delta m$, using the Part I data. Based on your analysis of the graph, what is the relationship between the mass difference and the acceleration of an Atwood's machine? Why does this work in terms of forces?

4. Plot a graph of acceleration *vs.* total mass, using the Part II data. Based on your analysis of the graph, what is the relationship between total mass and the acceleration of an Atwood's machine? Why does the acceleration decrease when the mass difference remains constant? How does this relate to Newton's 2nd law?

5. Develop a single expression for the acceleration of an Atwood's machine, combining the results of the previous two steps in the analysis. Is this expression consistent with Newton's laws? Why do you think so?

## EXTRA STUFF

1. Draw a free body diagram of $m_1$ and another free body diagram of $m_2$. Using these diagrams, apply Newton's second law to each mass. Assume that the tension is the same on each mass and that they have the same acceleration. From these two equations, find an expression for the acceleration of $m_1$ in terms of $m_1$, $m_2$, and $g$. Compare the expression to your result in Step 5 of Analysis.

2. For each of the experimental runs you made, calculate the expected acceleration using the expression you found with Newton's second law of motion and the specific masses used. Compare these figures with your experimental results. Are the experimental acceleration values low or high? Why?

3. How does the force exerted upward by the pulley change as the system begins accelerating? Why?

4. How does the tension in the string change as the masses start to move? Or does it? Why?