Name______________________________ Date________________

PRE-LAB PREPARATION SHEET FOR LAB 4: NEWTON'S LAWS

(*Due at the beginning of Lab 4*)

Directions:
Read over Lab 4 and then answer the following questions about the procedures.

1. How do you record force data from your sensor cart?

2. For an object of given mass, what is the relationship between the net force it experiences and its acceleration?

3. What does an inverse relationship look like on a graph? What does a linear relationship look like? Sketch both relationships and explain in words.

4. In Activity 1-2, you will collect data with the modified Atwood's machine, varying the mass and acceleration but keeping the tension while accelerating constant. When you increase the cart mass but keep the hanging mass constant, do you think the tension in the string increases, decreases, or stays the same? Give a reason why.

5. If you accelerate a 1 kg cart at a rate of 1 m/s^2, what net force are you applying?

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LAB 4:
NEWTON'S LAWS

OBJECTIVES

- To find out the relationship between force, mass, and acceleration
- To test the inertial mass definition
- To examine the SI units we use for mass, acceleration, and force

OVERVIEW

In this investigation you will examine how the motion of an object is related to the net force acting on it. You have examined objects moving at constant velocity and objects moving at changing velocities. You will now introduce a force sensor as a tool to measure the forces acting on an object and relate the force on an object to its acceleration and velocity.

The laws which describe the relationships between forces and the motion of objects to which they are applied are known as Newton's Laws. Newton's First Law states that an object in motion will remain in motion, and an object at rest will remain at rest, if no net force acts upon it. We will explore this in more detail in future labs.

Newton's Second Law states that if there is a net force acting upon an object, its motion will change. This change in motion, or acceleration, depends on both the net force and the mass of the object. In this lab, we will conduct experiments and collect data to reaffirm the mathematical relationships between these three variables (acceleration, net force, and mass). Observing these trends will also strengthen our intuition of how the variables relate to each other.

MATERIALS

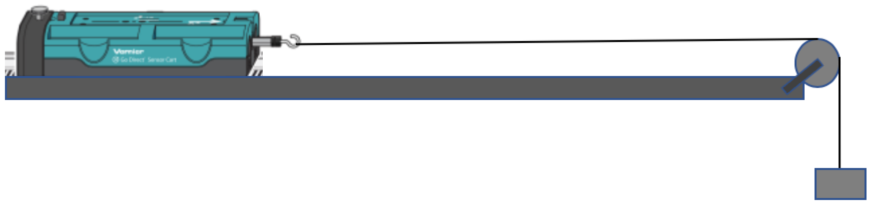
- Graphical Analysis application
- Low friction track
- Go Direct Sensor Cart
- Low-friction pulley and string
- Variety of masses to change the cart and hanging mass

INVESTIGATION 1: FORCE, MASS AND ACCELERATION

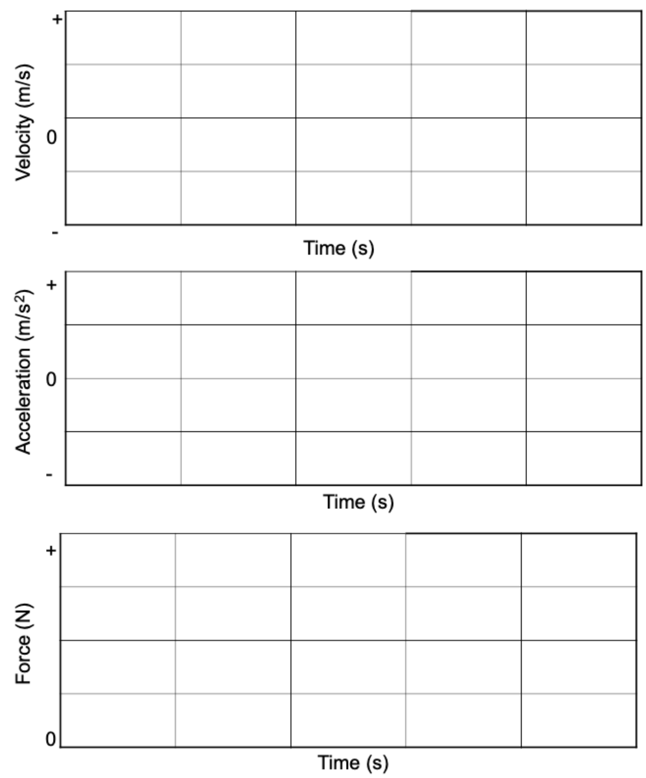
In this investigation you will examine what sort of net force applied to an object causes a steadily increasing velocity (constant acceleration).

Activity 1-1: Acceleration Force (Constant Cart Mass)

In this activity we will study the relationship between acceleration and force by keeping the third variable, mass, constant. We will use a sensor cart with a force hook attached by a long string to a hanging mass. The cart will sit on a track with negligible friction, so the hanging mass will apply net external force on the cart through the rope. As we change the hanging mass, the cart will record the force due to tension and the acceleration. We will record this data and find the relationship between them.



Prediction 1-1: Suppose you want to make a cart speed up steadily (with a constant acceleration). Describe in words and sketch dotted-line graphs of the velocity, acceleration, and force which you would expect.



1. Measure the cart mass. Record it in the second column of Table 1-1.

2. Set up the ramp, pulley, cart, string, and hanging mass on your table as seen in the above figure. Be sure that the ramp is level. The hanging mass should total 50 g.

3. Launch Graphical Analysis and go to Sensors (the bottom-right icon that looks like a plug). Click Sensor Channels. Select the check box for force, velocity, and X-axis acceleration, then click Done.

4. Click Data Collection Settings in the lower left-hand corner. Change End Collection to 3 s, then click Done. Click View, , and choose 3 Graphs. Make sure these graphs are velocity vs. time, acceleration vs. time, and force vs. time.

5. Place the sensor cart on the track, make sure it isn't moving and the rope is slack or unattached, then zero both acceleration and force. Click the Force meter and choose Zero. Click the X-axis acceleration meter and choose Zero.

6. Connect the string to the hook on the cart and to the hanging mass. Click Collect, and after a moment release the cart.

7. Print your results or sketch your results (solid lines) on the graphs on the previous page along with your prediction

8. Highlight the portion of the force graph when the cart is accelerating. Click on Graph Tools, , and choose View Statistics to find the mean value of the force. Record it in the first row of Table 1-1. Use the same approach to find the mean value of the acceleration while the cart is accelerating.

Question 1-1: What kind of force is needed to move the cart with a steadily increasing velocity: constant, increasing, or decreasing? Does the force graph agree with your prediction?

Question 1-2: Compare the force applied to the force sensor by the hanging mass during the moment the cart is at rest and the time when the cart is accelerating. Is one of those forces larger? (Keep in mind that the force sensor measures the tension in the string and not the weight of the hanging mass.)

Prediction 1-2: If you double the force applied to the cart, what will happen to its acceleration? Will it still be constant? How large will it be?

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Instructor

Test your prediction.

9. Increase the hanging mass to 100 g. Be sure to zero the force sensor with the string hanging loosely.

10. Press Collect and release the cart. Repeat Step (8) on your new dataset and record the acceleration and force values in Table 1-1.

Question 1-3: Did your graphs agree with your predictions? Explain any differences.

11. Sketch your new results with dashed lines on the same graphs with the previous run.

12. Accelerate the cart with a 150 gram hanging mass. Zero the force probe with the string slack, then attach the string. Press Collect and release the cart after a second. Record the acceleration and force values in Table 1-1.

13. Choose a fourth hanging mass value and repeat the data collection process to complete Table 1-1.

Hanging Mass (kg)	Measured Mass of Cart (kg)	Applied Force (N)	Acceleration (m/s^2)	Force/Accel. Ratio
50g				
100g				
150g				

Table 1-1

Question 1-4: Does there appear to be a mathematical relationship between acceleration and force for an object pulled with a constant mass? What is it? Justify your answer using the data in your table.

Activity 1-2: Accelerating a Cart with a Different Mass

Prediction 1-1: If the cart's mass were twice as large, and you accelerated it with the same tension force applied with 150 g of hanging mass, would the acceleration be different? In what way? Answer qualitatively and quantitatively.

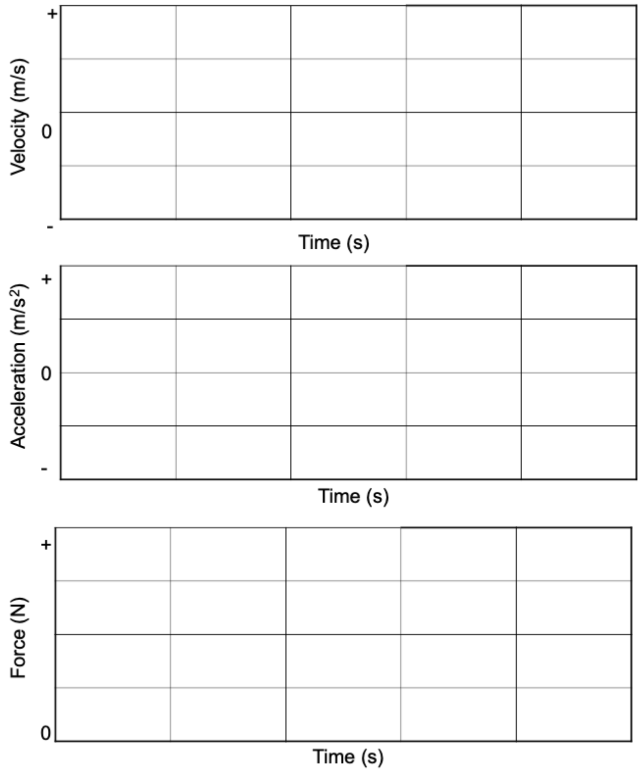
Instructor________

Test your prediction.

1. Add masses on top of the cart to double the overall mass of the cart.
New mass of the cart: ____________kilograms.

2. Zero the force probe with no force on it. Start with 150 g of hanging mass. Click Collect to record data while the cart and hanging mass are accelerating, then adjust the hanging mass and repeat the measurement until the tension force applied to the cart *while the system is accelerating* is the same (within +/- 0.02 N) as the case with 150 g of hanging mass and no additional mass on the cart. You may have to try a few times.

3. Sketch the graphs below. Also sketch the graphs for the less massive cart run (with 150 g hanging mass) with a dashed line.



Question 1-5: Did the graphs agree with your predictions? Explain any differences.

4. Fill in the first row of Table 1-2 with the third row from Table 1-1. Then go to Graph Tools, , and choose View Statistics to find the mean value of the force *while the cart is accelerating*. Do the same thing for acceleration and record this information in the first row of Table 1-1.

5. Complete Table 1-2 by repeating steps (1), (2), and (4), *making sure to adjust the hanging mass each time so that the tension while accelerating remains constant*.

Hanging Mass (kg)	Measured Mass of Cart (kg)	Applied Force (N)	Acceleration (m/s^2)

Table 1-2

Question 1-6: Looking at Table 1-2, does there appear to be a mathematical relationship between acceleration and mass for an object pulled with a constant force? What is it? Justify your answer using the data in your table.

Question 1-7: Why do you have to change the hanging mass to keep the tension in the string the same value while the system is accelerating?

Activity 1-3: Relationship Between Acceleration and Mass

1. Plot the acceleration and mass data from Activity 1-2 to find the relationship between the two variables. You may use Logger Pro, Microsoft Excel, or Graphical Analysis.

2. If using Graphical Analysis, go to New Experiment and choose Manual Entry to plot the data.

3. Input the cart mass values and the acceleration values in the table on the right. Adjust the axis labels to correctly display the variable and units.

4. Go to Graph Tools, , and choose Apply Curve Fit. Select the best-fit option and print your graph.

Question 1-8: What is the mathematical relationship between mass and acceleration when the applied force is kept constant? Are they linearly proportional? Inversely proportional? What happens to the acceleration when the mass increases and the force remains constant?

INVESTIGATION 2: FORCE AND MASS UNITS

Science is a language like any other and requires standard definitions to efficiently transmit information. In this and previous labs, you have been measuring variables such as position, velocity, acceleration, and now mass and force, using International System of Units (SI). Let us take a moment to consider these SI units, and what they are for force and mass.

On May 20, 1875, The International Treaty of the Meter was signed by seventeen countries, including the United States. Today, there are 7 internationally recognized base units whose measurements are completely based on physical constants of nature, and 22 derived units that are compounds of the 7 base units. In this class, we focus on variables that use three of those base units:

Length: a **meter (m)** is defined as the distance light travels in a vacuum in 1/(299,792,458) seconds, where 299,792,458 is the definition of the speed of light.

Time: a **second (s)** is defined by the amount of time for a cesium-133 atom to complete 9,192,631,770 particular transitions.

Mass: a **kilogram (kg)** is defined in terms of the Planck constant, a measurement of the smallest possible quantity of energy.

Force is measured in terms of a derived unit, the **Newton (N)**. One Newton is defined as the amount of force required to accelerate one kilogram of mass at a rate of one meter per second per second:

$$1\ \mathrm{N} = 1\ \mathrm{kg}\ {}^{\mathrm{m}}/_{s^2}$$

This provides the dimensional analysis for Newton's Second Law:

$$\Sigma\vec{F} = \mathrm{m}\vec{a} \qquad \text{or} \qquad {}^{\Sigma\vec{F}}/_{\vec{a}} = \mathrm{m}$$

Which tells us that the net external force, or the sum of all external forces, acting on a mass will cause its acceleration. The net-force-to-acceleration ratio on the right is called the inertial mass of a system. We are going to test this relationship with the data we have collected.

Activity 2-1: Inertial Mass from Acceleration and Force

1. If you haven't yet, fill in the last column of Table 1-1 by calculating the force/acceleration ratio. Copy the same numbers into Table 2-1 below.

Question 2-1: What was the "Applied Force" recorded in Table 1-1?

Question 2-2: What can you say about the force/acceleration ratio? How does it compare to the cart mass that you measured?

2. Fill in the Force/Accel. Ratio column. Calculate the error between the measured and calculated mass of the cart for your data sets in Table 2-1.

$$\text{Percent Error} = \frac{|\text{Accepted} - \text{Measured}|}{\text{Accepted}} \times 100\%$$

Hanging Mass (kg)	Measured Mass of Cart (kg)	Force/Accel. Ratio	Percent Error on Mass
50g			
100g			
150g			
Average Percent Error on Mass:			

Table 2-1

Question 2-3: How close is your predicted and measured mass, on average? Discuss sources of uncertainty or error in your measurements of acceleration and force.

Question 2-4: A force of 4.4 N is applied to an object, and that object then accelerates at a rate of 2.5 m/s^2. If friction is negligible, what is the mass of that object in kilograms? Show your calculation.

Activity 2-2: Newton's Laws

Question 2-5: Newton's first law outlines the conditions under which an object either moves at constant velocity or remains at rest. Write Newton's first law in your own words, in terms of the net force acting on an object.

Question 2-6: Now write Newton's first law in terms of a series of equations. What is $\Sigma\vec{F}$ for Newton's first law? What does $\vec{a} =$ in that case? What does $\vec{v} =$ based on the acceleration?

Question 2-7: Write Newton's second law in your own words, in terms of the net force acting on an object.

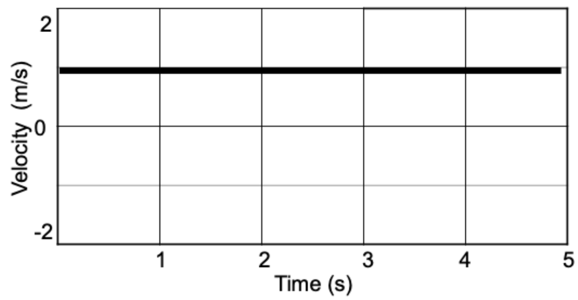
Question 2-8: Now write Newton's second law in terms of a series of equations. What is $\Sigma\vec{F}$ for Newton's second law? What does $\vec{a} =$ in that case? What does $\vec{v} =$ based on the acceleration?

Question 2-9: Write Newton's third law in your own words. Avoid "equal and opposite" and "action and reaction."

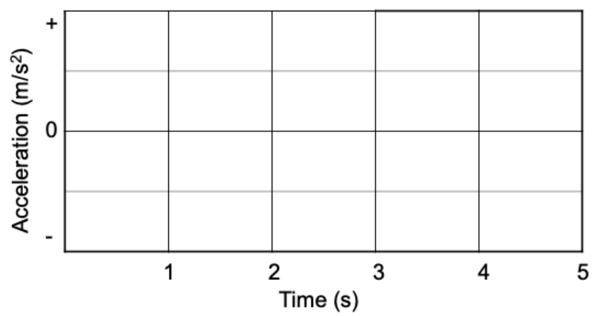
Name________________________________Date_____________________Partners_______________________________

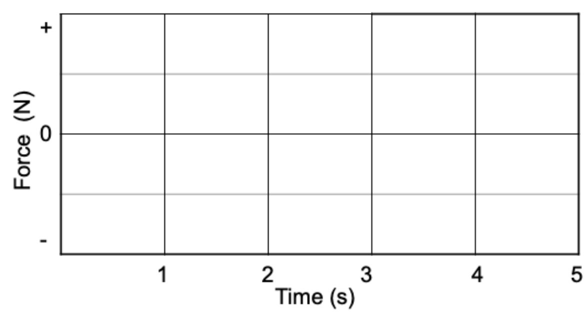
HOMEWORK FOR LAB 4: NEWTON'S LAWS

A cart can move along a horizontal line. It is pulled so that it moves with the velocity shown below.



1. Assuming that friction it not negligible, sketch on the axes below the acceleration of the cart and the net force it experiences.



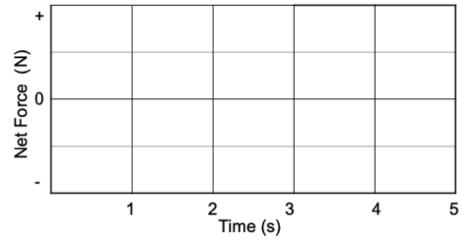


2. Explain why your graphs look that way. How can a cart maintain constant velocity if a non-negligible friction force is acting on it?

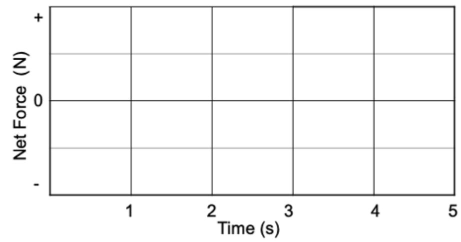
3. Now suppose that the cart had twice the mass. What would change in this situation? What changes would we see in the graphs above, and why?

Question 4-8 refer to an object which can move in either direction along a horizontal line (initially along the positive x-axis). Assume that friction is so small that it can be ignored. Sketch the shape of the graph of the net force applied to ab object which would produce the motion described.

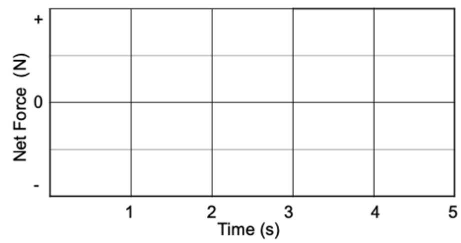
4. The object moves away from the origin with a constant velocity



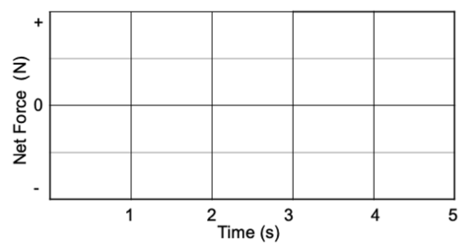
5. The object moves toward the origin with a constant velocity.



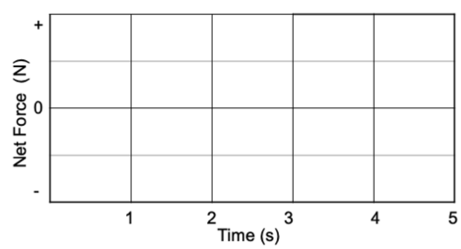
6. The object moves away from the origin with a steadily increasing velocity.



7. The object moves away from the origin, speeds up and then slows down.



8. The object moves toward the origin with a steadily increasing velocity.



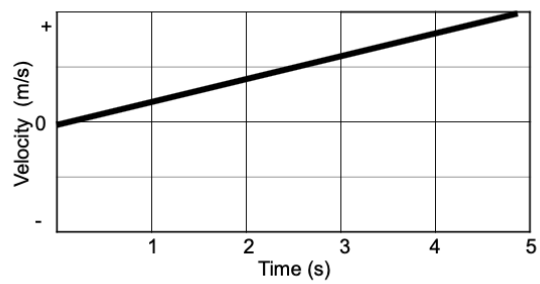
Questions 9-11 refer to a penny which is tossed in the air. It moves upward, reaches the highest point, and falls back downward. Consider the positive direction to be upward.

For each of the three parts of the penny's motion, use one of the following choices to indicate whether the net force on the penny is

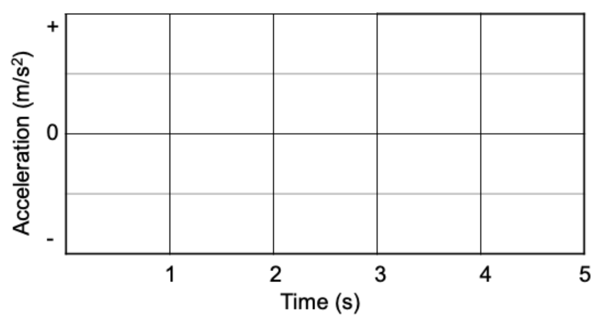
A. Upward
B. Downward
C. Zero

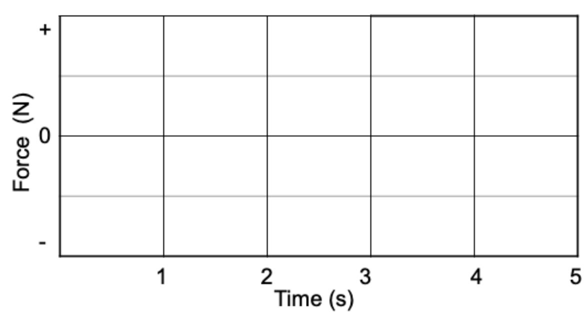
9. _______ The penny is moving upward and slowing.
10. _______ The penny is at its highest point.
11. _______ The penny is moving downward and speeding up.

Questions 12-13 refer to an object which can move along a horizontal line (the positive distance axis). Assume that friction is negligible in this case. The object's velocity vs. time graph is shown below.



12. Sketch the shapes of the acceleration and force graphs on the axes below.





13. Now suppose that the mass of this object was twice a large, but the velocity vs. time graph remained unchanged. Sketch the acceleration and net force on the same axes above. Explain any differences, or why there aren't any differences.