Name________________________________Date_____________________
Partners______________________________

Physics 230
Newton's Laws

Materials
Low friction track, two carts with force probe mounts, string, 50 gram hanging mass, 1 kg mass, pulley, two force probes, two hook connectors for a the force probe, two rubber knob collision detectors for the force probes, motion sensor, LabPro ADC and a computer. In addition, you need the following cords: power cord for LabPro, cord to connect motion sensor to LabPro, cord to connect LabPro to computer

In this lab you should

- Be introduced to the concept and process of calibrating a measurement tool.
- Review issues of uncertainty in measurement including the use and meaning of a standard deviation.
- Learn how to use a force probe (strain gage) with an ADC (analog to digital converter) and data collection software to measure force.
- Explore how the motion of an object is related to the forces applied to it.
- Find a mathematical relationship between the force applied to an object and its acceleration.
- Explore Newton's third law.

Introduction
In the previous lab you used a motion detector, analog to digital converter (ADC) and data collection software to create position vs. time, velocity vs. time, and acceleration vs. time graphs for various motions. In that lab you were not concerned with *how* you got the objects to move; you focused on describing the motions in terms of the object's velocity and acceleration. That is, you didn't worry about what **forces** (pushes or pulls) acted on the objects. In this investigation you will explore the concept of a constant force and what types of motion are produced when a constant force acts on an object.

The connection between force and motion is Newton's second law which states that the vector sum of all forces acting on an object is equal to the object's mass multiplied by its acceleration. The vector sum of all forces acting on the object is called the **net force** on the object. Consequently, we can write Newton's second law as $\vec{F}_{net} = \sum \vec{F} = m\vec{a}$.

In this lab we will be working with low friction carts and tracks and so friction is small enough to be ignored. Consequently, the only force acting on the cart in horizontal direction will be the force applied to a force probe attached to the cart. The vertical forces on the cart sum to zero and so the net force acting on the cart is just the force applied to the probe.

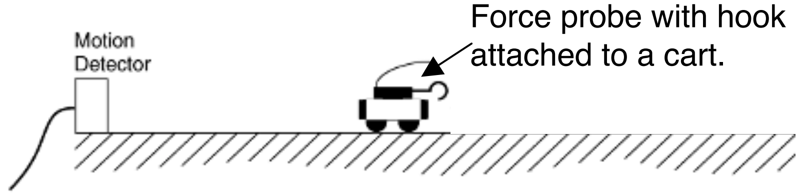
As the name implies, a force probe is a tool used to measure force. The force probe that you will use today is a version of a device called a **strain gauge**. Strain gauges are used widely in science and engineering. In general, a strain gauge contains a piece of metal which is temporarily deformed (stretched or compressed) when a force is applied. When the piece of metal is deformed one of its electrical properties (its resistance) changes. This change is detected and processed by the analog to digital converter (the LabPro) and then interpreted by the data collection software to produce an accurate and reliable measure of the force.

Before using the force probe we will check that the device is properly calibrated. **Calibration** is basically a comparison between known values and values measured by the device. If the measurements and known values can be made to match, we have confidence that the device is making accurate measurements and say the device is "calibrated". Often, the calibration process is a "two-point" calibration. This means that the comparison between known and measured values occurs for two values. In the first activity below we check the probe's calibration using the two points 1) zero force applied and 2) a measurement of second known force based on the weight of an object.

PROCEEDURE

INVESTIGATION 1: RELATING FORCE AND ACCELERATION
Activity 1-1: Checking the Force Probe Calibration

1. Check that your equipment set-up looks like that shown below. There should be a hook on the force probe and only one cart on the track. (The hook screws in and can be exchanged with a rubber knob—both the hook and knob should be on your table.) You should have only the one force probe plugged into the LabPro in the port labeled CH1. The motion sensor should plugged into the port labeled DIG1. Now look at the force probe itself and make sure that the sensitivity button is set to 10 N. Open the file **N3 long.cmbl** in the PHY230 folder on the desktop. There should be two force vs. time graphs shown with a time scale that goes to 10 seconds. The collect button that looks like an arrow at the top of the screen should be green. *(If the collect arrow is not green, check that all the cords are connected, the LabPro is pulled into the electrical outlet and is connected to the computer. If the collect button is still not green, unplug the LabPro and plug it back in. Then go to Experiment, connect interface, LabPro, com1. If this doesn't work call your instructor.)*



2. You are now ready to check the calibration of the force probe. For the first point in your calibration check you should use a force of 0 N. That is, you will check that your force probe reads 0 N when no force is applied to the probe hook. (The hook is where the applied force is measured.) To test this, make sure that noting is attached to or touching the hook on the end of the force probe. Click the collect button and see if the force detected is exactly zero.

Since forces are detected by the computer system as *changes* in an electronic signal, it is important to let the computer know what the signal looks like when the force probe has no force pushing or pulling on it. This process is called "**zeroing.**" Also, the electronic signal from the force probe can change slightly from time to time as the temperature changes or if it has gotten banged. Therefore, you should **zero** your force probe often. To do this, remove anything that may be attached to the force probe and then click the zero button at the top of the screen. Zero the force probe ONLY, not the motion sensor. Sometimes you need to zero the force probe more than once to actually get it measure zero force with zero force applied. But, if properly zeroed, your force graph should read zero if you click collect with nothing attached to the force probe.

Zero your force probe as discussed in the box above.

3. Now pick up the cart and hold it so that the force probe is vertical and the hook is at the bottom. Add a mass to the hook of the probe and let it hang vertically. Record the force probe reading. (Use the Analyze-Statistics function to get an average).

F=__________N

4. Calculate the force of gravity on the mass hanging from the hook. (This force is also known as the weight of the mass. weight =mass in kg x 9.8 m/s^2).

Mass = _________g = __________Kg

F_g= _________N.

5. If the probe is properly calibrated your measurement in #3 and calculation in #4 should agree within about 2%. Calculate the percent difference between the two measurements and record it here. If it is more than 5% check with your instructor.

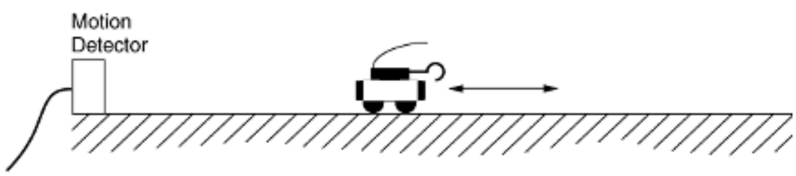
% difference________________________

Now you can use the force probe to apply forces to the cart and measure the force at the same time. You can also use the motion detector, as in the previous two labs, to examine the motion of the object. In this way you will be able to explore the relationship between motion and force.

Activity 1-2: Pushing and Pulling a Cart

In this activity you will move a low friction cart with your hand by pushing and pulling on the hook end of the force probe. You will measure the force, velocity, and acceleration. Then you will be able to look for mathematical relationships between the applied force and the velocity and acceleration, to see whether either is (are) related to the force.

1. Set up the cart, force probe, and motion detector on a smooth level track as shown below.



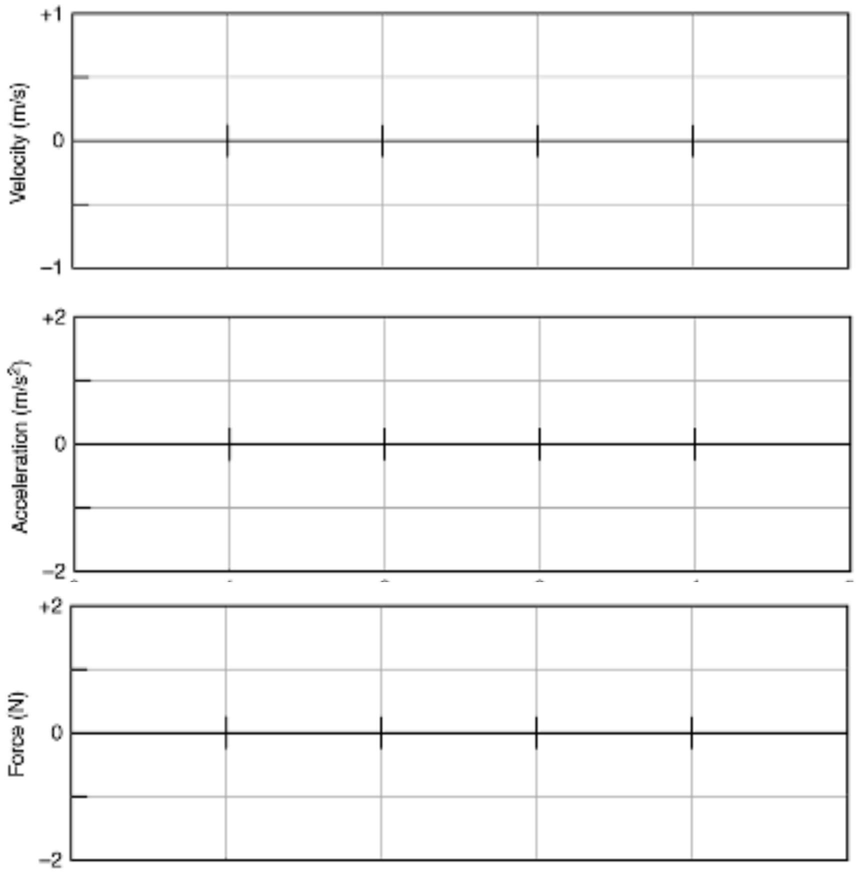
The force probe should be fastened *securely* to the cart. As you work through all the motions below be sure to always keep the nearest part of the cart at least ½ meter from the motion detector. Also, keep your hand and the force probe cord out from between the motion detector and the cart.

Prediction 1-2-1: Suppose you grasp the force probe hook and move the cart forward and backward in front of the motion detector. Do you think that either the velocity or the acceleration graph will look like the force graph? Is either of these motion quantities related to force? (That is to say, if you apply a changing force to the cart, will the velocity or acceleration change in the same way as the force?) Explain.

2. To test your predictions**, open the experiment file called N2.cmbl** in the PHY230 folder on the desktop**.** This will set up velocity, force, and acceleration axes with a convenient time scale as shown below.

3. **Zero** the force probe. Then, grasp the force probe hook and **begin graphing**. When you hear the clicks, quickly pull the cart away from the motion detector and quickly stop it. Then quickly push it back toward the motion detector and again quickly stop it. Pull and push the force probe hook along a straight line along the track. *Do not twist the hook. Be sure that the cart never gets closer than 0.5 m away from the motion detector and keep your hand and the force probe cord out from between the motion detector and cart.*

4. Carefully sketch your graphs on the axes below.



Question 1-2-1: Does either graph–velocity or acceleration–resemble the force graph? Which one?

5. Use the analyze feature of the software to make a measurement of the acceleration at one moment in time. Make a measurement of force at the same time. Record these measurements in the table on the next page. Calculate the mass of the cart based on Newton's second law ($\vec{F}_{net} = m\vec{a}$). Take 4 more pairs of simultaneous acceleration and force measurements and record them in the table. Calculate the mass of the cart for each. Calculate the average and standard deviation for your mass calculations.

Acceleration (m/s^2)	**Force (N)**	**Mass (kg)**

Average Mass ____________________

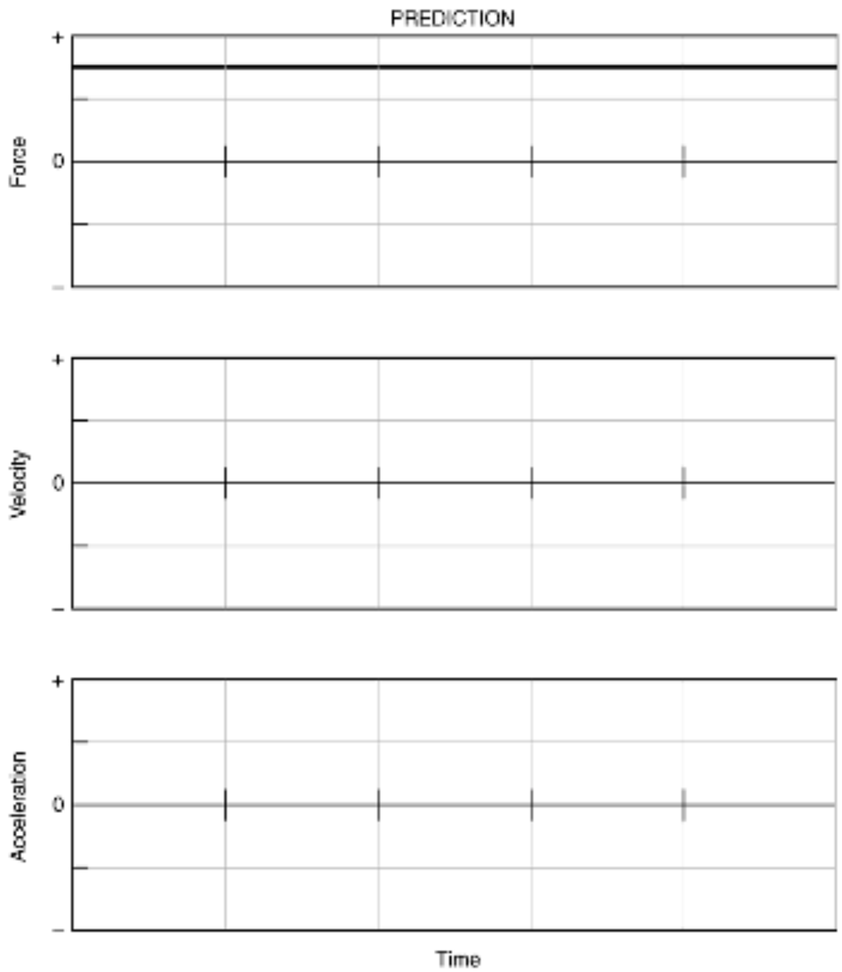
Standard Deviation_________________

Question 1-2-2: Explain with words alone the meaning of your average and standard deviation results above.

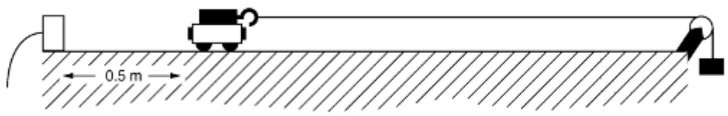
Question 1-2-3: Based on your calculations and observations, does it appear that there is a mathematical relationship between either applied force and velocity, applied force and acceleration, both, or neither? Explain.

Activity 1-3: Speeding Up Again

Prediction 2-2: Suppose that you have a cart with very little friction and you pull this cart with a constant force as shown below on the force—time graph. Sketch on the axes below your predictions of the velocity—time and acceleration—time graphs of the cart's motion.



1. Set up the track, pulley, cart, string, motion detector, and force probe as shown below. The hanging mass should be 50 grams.

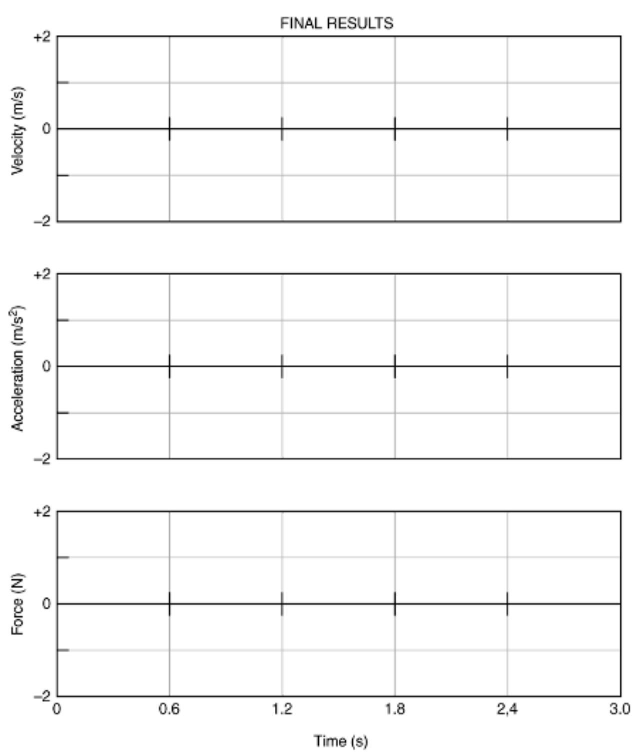


Remember that the back of the cart must always be at least 0.5 m from the motion detector and keep your hand and the force probe cord out of the line between the motion detector and cart.

Zero the force probe with the string hanging loosely so that no force is applied to the probe.

2. Test your predictions. **Begin graphing.** Release the cart after you hear the clicks of the motion detector. *Be sure that the cable from the force probe is not seen by the motion detector,* ***<u>and that it doesn't drag or pull the cart</u>****.* Repeat until you get good graphs in which the cart is seen by the motion detector over its whole motion.

3. Sketch the actual velocity, acceleration, and force graphs on the axes that follow. Draw smooth graphs; don't worry about small bumps. Record only data for the time during which the cart is moving.



Question 1-3-1: After the cart is moving, is the force that is applied to the cart by the string constant, increasing, or decreasing? Explain based on your graph.

Question 1-3-2: How does the acceleration graph vary in time? Does this agree with your prediction? Does a constant applied force produce a constant acceleration?

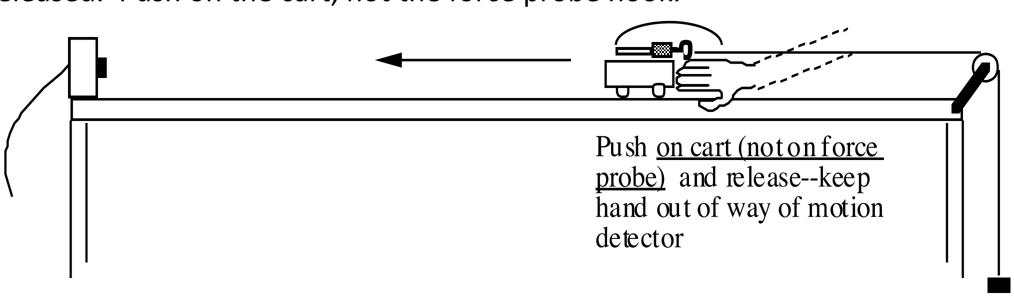
Question 1-3-3: How does the velocity graph vary in time? Does this agree with your prediction? What kind of change in velocity corresponds to a constant applied force?

Question 1-3-4: If you increased the force applied to the cart by a factor of 10, how would you expect the acceleration—time graph of the cart's motion to change?

Question 1-3-5 If you increased the force applied to the cart by a factor of 10, how would you expect the velocity—time graph of the cart's motion to change?

Activity 1-4: Slowing Down Moving Toward the detector

1. Set up the cart, ramp, pulley, hanging mass, and motion detector as shown in the diagram that follows. The cart now starts it motion at the far end of the track. Now when you give the cart a push toward the motion detector, it will slow down after it is released. Push on the cart, not the force probe hook.



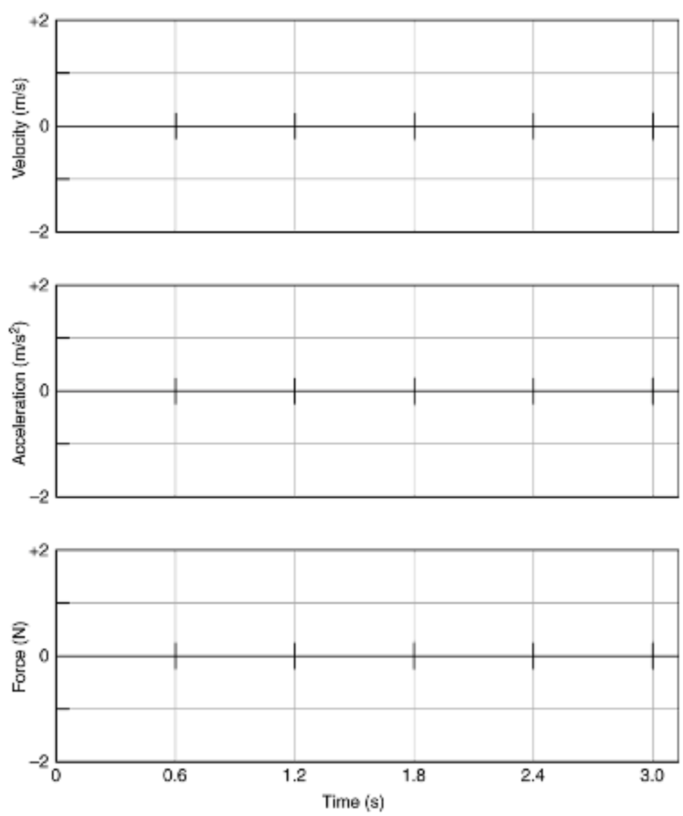
STOP THE CART BEFORE IT REVERSES DIRECTION OR GETS CLOSER THAN ½ METER FROM THE DETECTOR. DO NOT PUSH ON THE HOOK.

Prediction 1-4-1: Suppose that you give the cart a push toward the left and release it. If the positive x direction is away from the detector (toward the right in the figure), what are the signs of the velocity, force, and acceleration **after the cart is released and is moving toward the right**?

Velocity Force Acceleration

1. Test your predictions. Zero the force probe with nothing attached to it. **Begin graphing**, and when the motion detector starts clicking, give the cart a short push toward the detector and then let it go. *Be sure to keep your hand out of the region between the motion detector and the cart.* **Stop the cart before it reverses its direction or gets too close.**

2. Sketch your velocity, acceleration, and force graphs on the axes above. Draw smooth lines and curves as always. Don't worry about any small bumps.



Question 1-4-1: Did the signs of the velocity, force, and acceleration agree with your predictions? If not, can you now explain the signs? Ask your instructor if you are confused.

Question 1-4-2: Did both the velocity and acceleration have the same sign? Were the velocity and acceleration in the same direction? Explain.

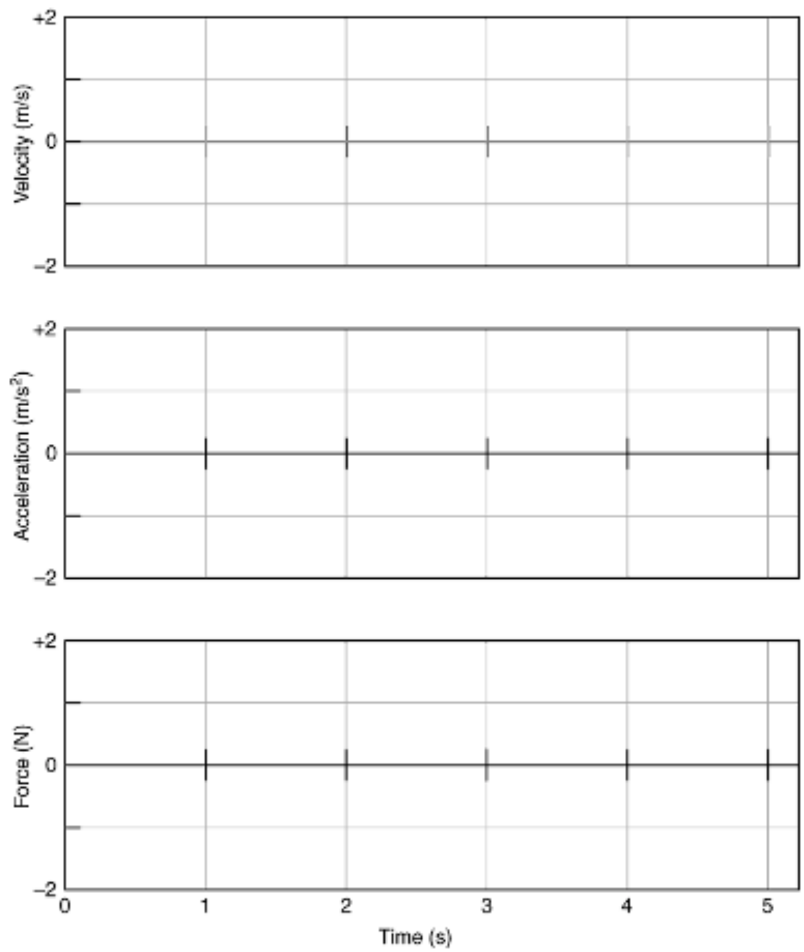
Question 1-4-3: Did the force and acceleration have the same sign? Were the force and acceleration in the same direction?

Question 1-4-4 After you released the cart, was the force applied by the falling mass constant, increasing, or decreasing? Explain why this kind of force is necessary to produce a linear velocity graph. .

Activity 1-5: Reversing Direction

1. Suppose that you use the same setup as in the previous activity, but now you let the cart reverse direction. That is, you give the cart a push toward motion detector, release it, and let it move toward the detector, **reverse direction, and head back away from the motion detector**. Sketch on the axes that follow with dashed lines your predictions for the velocity, acceleration, and force after the cart leaves your hand and before you stop it. Mark on your prediction the time at which the cart reverses direction.

2. Carry out this experiment. Sketch your observed graphs with solid lines on the axes that follow. Mark on your graphs the time at which the cart reverses direction.

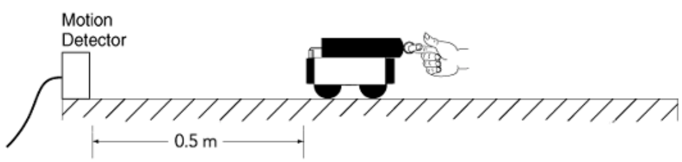


Question 1-5-1: . Describe the force and acceleration at the moment when the cart reverses direction. How are they different just before and just after the turn around?

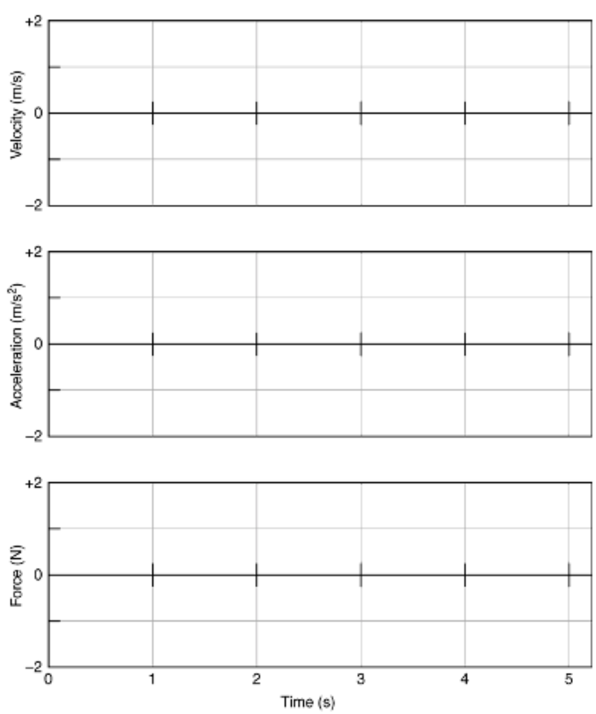
Question 1-5-2: Based on your knowledge of acceleration and force, explain why the force and acceleration have the signs they have at the moment the cart reverses direction.

Activity 1-6: Once a Pull, Always a Pull?
Remove the string and hanging mass from the hook on the force probe.

Prediction 3-4: Suppose that you give the cart a quick pull to start it moving away from the motion detector (by pulling on the force probe hook) and release it. Sketch with dashed lines on the axes that follow the velocity—time, acceleration—time and force—time graphs for the motion of the cart. Indicate the moment when the cart was released with an arrow.



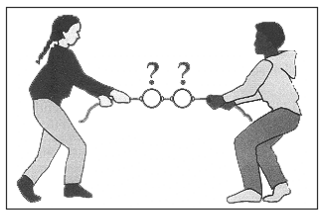
1. Test your predictions.. Be sure that the force probe cord won't interfere with the cart's motion and won't be seen by the motion detector. As always, **zero** the force probe just before graphing. **Begin graphing**. After the motion detector starts clicking, give the cart a short pull on the hook of the force probe in the direction away from the motion detector, and then let the cart go.Sketch your graphs on the axes with solid lines. Indicate with an arrow the time when the pull stopped.



Question 1-6-1: Does the force become zero when the pull ends? What happened to the acceleration then? What happens to the velocity?

This is experiment can be considered a demonstration of Newton's 1st Law: To make the cart move with a constant velocity you needed to apply a force to get it moving, but no applied force needed to keep it moving at a constant velocity.

INVESTIGATION 2: NEWTON'S THRID LAW



Interactions between objects, including collisions and explosions, never involve just one force. Consequently, we turn our attention to the mutual forces of interaction between two or more objects. This will lead us to a very general law known as *Newton's third law*, which relates the forces of interaction exerted by two objects on each other.

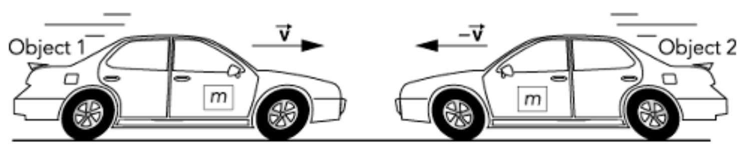
There are many situations where objects interact with each other, for example, during collisions. In this investigation we want to compare the forces exerted by the objects on each other. In a collision, both objects might have the same mass and be moving at the same speed, or one object might be much more massive, or they might be moving at very different speeds. Next we consider questions such as: What factors might determine the forces the objects exert on each other? Is there some general law that relates these forces?

As usual you will be asked to make some predictions about interaction forces and then be given the opportunity to test these predictions. In order to test your predictions you will need to change the hook on the force probe to the rubber knob. The hook and rubber knob screw in. You will also need to add a second cart with force probe to your set-up and plug the second force probe into CH2 on the LabPro. Be sure that both force probes have the switch on top set to 10 N. You will no longer need the motion detector. You can remove that from the track.

ACTIVITY 2-1: COLLISION INTERACTION FORCES

Prediction 2-1-1: Suppose two objects have the same mass and are moving toward each other at the same speed so that $m_1 = m_2$ and $\vec{\mathbf{v}}_1 = -\vec{\mathbf{v}}_2$ (same speed, opposite direction).

$$m_1 = m_2 \quad \text{and} \quad \vec{\mathbf{v}}_1 = -\vec{\mathbf{v}}_2$$

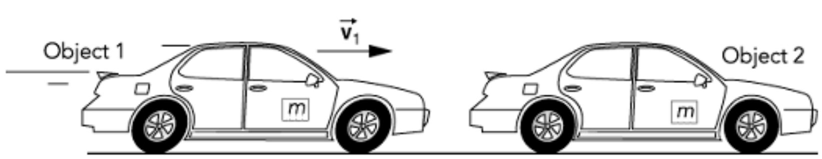


Predict the relative magnitudes of the forces between object 1 and object 2 during the collision. Place a check next to your prediction.

______Object 1 exerts a larger force on object 2.
______The objects exert the same size force on each other.
______Object 2 exerts a larger force on object 1.

Prediction 2-1-2: Suppose the masses of two objects are the same and that object 1 is moving toward object 2, but object 2 is at rest.

$$m_1 = m_2 \quad \text{and} \quad \vec{\mathbf{v}}_1 \neq 0, \vec{\mathbf{v}}_2 = 0$$

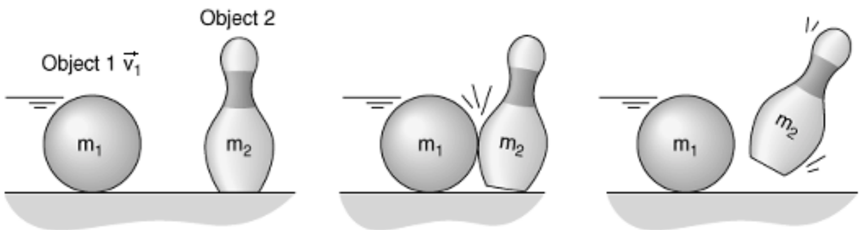


Predict the relative magnitudes of the forces between object 1 and object 2 during the collision.

______Object 1 exerts a larger force on object 2.
______The objects exert the same size force on each other.
______Object 2 exerts a larger force on object 1.

Prediction 2-1-3: Suppose the mass of object 1 is greater than that of object 2 and that it is moving toward object 2, which is at rest.

$$m_1 > m_2 \qquad \text{and} \qquad \vec{\mathbf{v}}_1 \neq 0, \vec{\mathbf{v}}_2 = 0$$

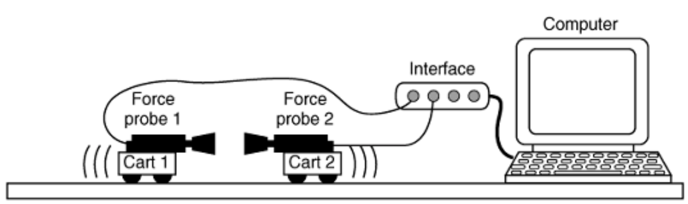


Predict the relative magnitudes of the forces between object 1 and object 2 during the collision.

______Object 1 exerts a larger force on object 2.
______The objects exert the same size force on each other.
______Object 2 exerts a larger force on object 1.

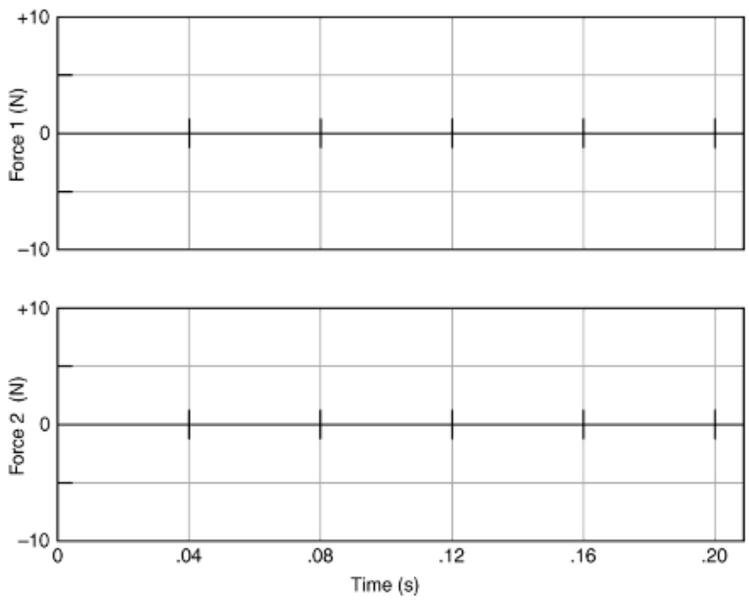
To test the predictions you made you can study *gentle* collisions between two force probes attached to carts. You can add masses to one of the carts so it has significantly more mass than the other. To make these observations of interactions you will need the following equipment:

1. Set up the apparatus as shown in the following diagram.



The force probes should be securely fastened to the carts. Probes should be plugged into CH1 and CH2 on the LabPro. You no longer need the motion detector so that can be removed from the track. The hooks should be removed from the force probes and replaced by rubber knobs, which should be *carefully aligned* so that they will collide head-on with each other.

2. **Open the experiment file called N3 short.cmbl in the PHY230 folder** on the desktop. The graphs displayed should look like those shown on the next page. The software will be set up to measure the forces applied to each probe with a very fast data collection rate of 4000 points per second. (This allows you to see all of the details of the collision which takes place in a very short time interval.) The software will also be set up to be **triggered**, so that data collection will not start until the carts actually collide.



3. **Zero** both force probes. **Reverse the sign** of force probe 2 since a push on it is negative (toward the left) if needed.

4. Use the two carts to explore various situations that correspond to the predictions you made about interaction forces. Your goal is to find out under what circumstances one cart exerts more force on the other. Be sure to **zero** the force probes before each collision. Also be sure that you only push the carts gently toward each other so that the forces during the collisions do not exceed 10 N.. Try these collision:

(a) Two carts of the same mass moving toward each other at about the same speed. Are the forces equal in magnitude? Is this what you expected?

(b) Two carts of the same mass, one at rest and the other moving toward it. Are the forces equal in magnitude? Is this what you expected?

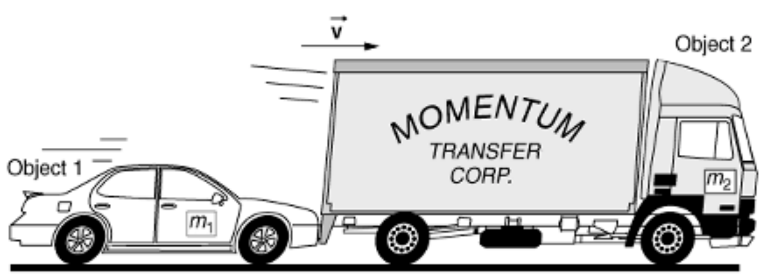
(c) One cart with an extra 1 Kg mass on top (so about twice as massive as the other) moving toward the other cart, which is at rest. Are the forces equal in magnitude?

Question 1-1: What can you conclude about forces of interaction during collisions? How do forces compare on a moment by moment basis during each collision?

Question 1-2: Do you think that there is anything that you could do to make these interaction forces unequal in magnitude? Explain.

EXTENTION Activity 2-2: Other Interaction Forces

Interaction forces between two objects occur in many other situations besides collisions. For example, suppose that a small car pushes a truck with a stalled engine, as shown in the picture. The mass of object 1 (the car) is much smaller than object 2 (the truck).



At first the car doesn't push hard enough to make the truck move. Then, as the driver pushes harder on the gas pedal, the truck begins to accelerate. Finally, the car and truck are moving along at the same constant speed.

Prediction 2-2-1: Place a check next to your predictions of the relative magnitudes of the forces between objects 1 and 2.

Before the truck starts moving:

______the car exerts a larger force on the truck.
______the car and truck exert the same size force on each other.
______the truck exerts a larger force on the car.

While the truck is accelerating:

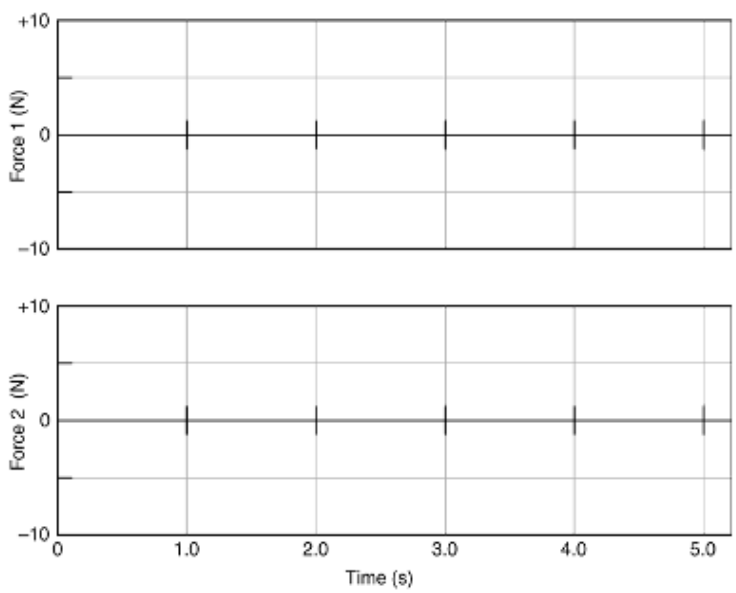
______the car exerts a larger force on the truck.
______the car and truck exert the same size force on each other.
______the truck exerts a larger force on the car.

After the car and truck are moving at a constant speed:

______the car exerts a larger force on the truck.
______the car and truck exert the same size force on each other.
______the truck exerts a larger force on the car.

Now test your predictions.

1. Open the file N3 long.cmbl in the PHY230 folder to display the axes that follow. The software is now set up to display the two force probes at a slower data rate of 20 points per second. The trigger setting is shut off so data collection once again begins when you click the collect button.



2. Use the same setup as in Activity 2-1 with the two force probes mounted on carts. Add the 1 kg mass to cart 2 (the truck) to make it much more massive than cart 1 (the car).

3. **Zero** both force probes just before you are ready to take measurements.

4. Your hand will be the engine for cart 1. Move the carts so that the rubber knobs are touching, and then **begin graphing**. When graphing begins, push cart 1 toward the right. At first hold cart 2 so it cannot move, but then allow the push of cart 1 to accelerate cart 2, so that both carts move toward the right, finally at a constant velocity.

5. Sketch your graphs on the axes above.

Question 2-2-1: How do your results compare to your predictions? Is the force exerted by cart 1 on cart 2 (reading of force probe 2) significantly different from the force exerted by cart 2 on cart 1 (reading of force probe 1) during any part of the motion? Explain any differences you observe between your predictions and your observations.

Question 2-2-2: Explain how cart 2 is able to accelerate. Use *Newton's second law*, and analyze the combined (net) force exerted by all the forces acting on it. Is there a nonzero net force?