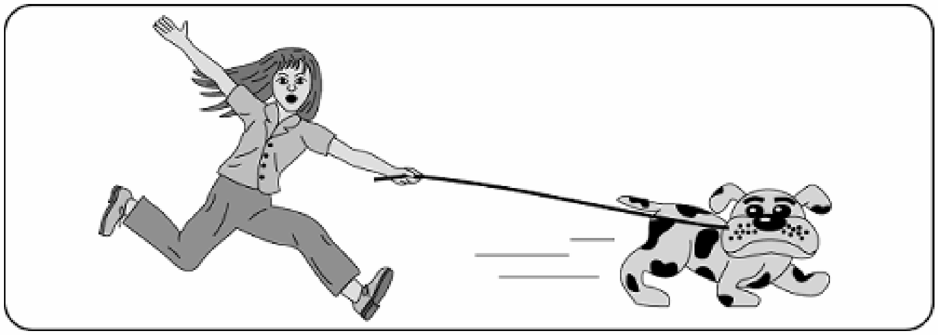
Name______________________________Date________________Partners______________________________

LAB 4:
FORCE AND MOTION



A vulgar Mechanik can practice what he has been taught or seen done, but if he is in an error he knows not how to find it out and correct it, and if you put him out of his road, he is at a stand; whereas he that is able to reason nimbly and judiciously about figure, force and motion, is never at rest til he gets over every rub.

–Isaac Newton

OBJECTIVES

- To develop a method for measuring forces reliably.
- To learn how to use a force probe to measure force.
- To explore how the motion of an object is related to the forces applied to it.
- To understand the relationship between the direction of the force applied to an object and the direction of the acceleration of the object.
- To understand how different forces can act together to make up a *combined force*. This combined force is that which changes an object's motion according to *Newton's second law.*
- To understand the motion of an object with no net force applied to it and how *Newton's first law* describes this motion.
- To find a mathematical relationship between the acceleration of an object and its mass when a constant force is applied–*Newton's second law*.
- To develop consistent statements of *Newton's first* and *second laws of motion* for one-dimensional motion (along a straight line) for any number of one-dimensional forces acting on an object.
- To understand the motion of an object with no net force applied to it and how *Newton's first law* describes this motion.

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OVERVIEW

In the previous labs, you have used a motion detector to display position—time, velocity—time, and acceleration—time graphs of different motions of various objects. You were not concerned about how you got the objects to move, that is, what forces ("pushes" or "pulls") acted on the objects.
From your own experiences, you know that force and motion are related in some way. To start your bicycle moving, you must apply a force to the pedal. To start up your car, you must step on the accelerator to get the engine to apply a force to the road through the tires.

But exactly how is force related to the quantities you used in the previous lab to describe motion–position, velocity, and acceleration? In this lab you will pay attention to forces and how they affect motion. You will first develop an idea of a force as a push or a pull. You will learn how to measure forces. By applying forces to a cart and observing the nature of its resulting motion graphically with a motion detector, you will come to understand the effects of forces on motion.

Another major goal of this lab is to continue to develop the relationship between force and acceleration: the first two of Newton's famous laws of motion. In Investigation 3, you will explore motions in which the applied force (and hence the acceleration of the object) is in a different direction than the object's velocity. In such a case the force will cause the object to slow down.

What if a force were applied to an object having a larger mass? A smaller mass? How would this affect the acceleration of the object?

Comment: Since forces are detected by the computer system as *changes* in an electronic signal, it is important to have the computer "read" the signal 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. Therefore, if it is possible to **zero** your force probe, it is a good idea to do so with nothing attached to the probe before making each measurement. To do that, push "tare" on the side of the force probe.

INVESTIGATION 1 MOTION AND FORCE

You can use the force probe to apply known forces to an object. 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. You will need the following additional materials:

- motion detector
- cart with very little friction
- masses to increase cart's mass to 1 kg (rectangular brass pieces);
  0.5 kg masses also rectangular
- 2-m motion track
- low-friction pulley, lightweight string, table clamp, variety of hanging masses

Activity 1-1: Pushing and Pulling a Cart

In this activity you will move a low - friction cart by pushing and pulling it with your hand. 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

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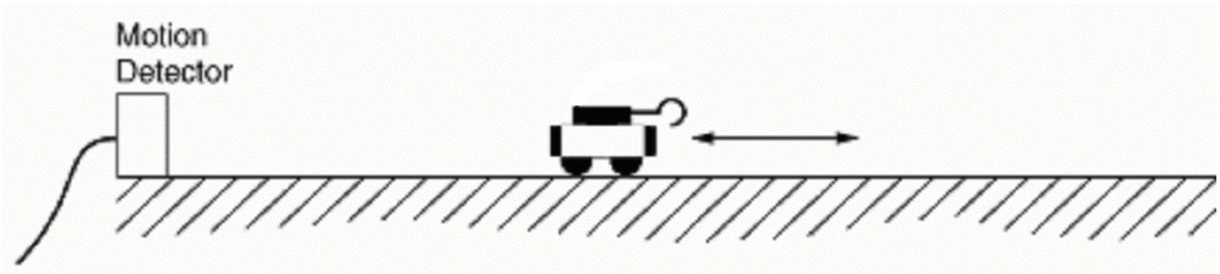
(are) related to the force.

1. Set up the cart, force probe, and motion detector on the 2-m track as shown below. The cart should have a mass of *about* 1 kg with force probe included. Use the specially constructed thin brass pieces to place in the tray on top of the force probe to reach 0.5 kg.



The force probe should be fastened *securely* to the cart *so that its body and cable do not extend beyond the end of the cart facing the motion detector. (Tape the force probe cable back along the body to ensure that it will not be seen by the motion detector.)*

Prediction 1-1: Imagine that 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 quantities related to force? (That is to say, if you apply a changing force to the cart, will the graph of the velocity or acceleration resemble the graph of the force?) Explain.

2. To test your predictions, open the experiment file called **Motion and Force L4.2-1.** This will set up velocity, force, and acceleration axes with a convenient time scale of 5 s.

3. **Zero** the force probe as described previously. Grasp the force probe hook and **begin graphing**. When you hear the clicks, quickly pull the cart away from the motion detector, let it roll on its own for a couple of seconds, then quickly stop it. Pull and push the force probe hook along a straight line parallel to the ramp. *Do not twist the hook. Be sure that the cart never gets closer than 0.2 m to the motion detector.*

4. **Print** out one copy of the graph for your group and include it with your report.

Question 1-1: Does either graph–velocity or acceleration–resemble the force graph? Which one? Explain why or why not.

Question 1-2: Based on your 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 1-2: Speeding Up Again

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You have seen in the previous activity that force and acceleration seem to be related. But just what is the relationship between force and acceleration?

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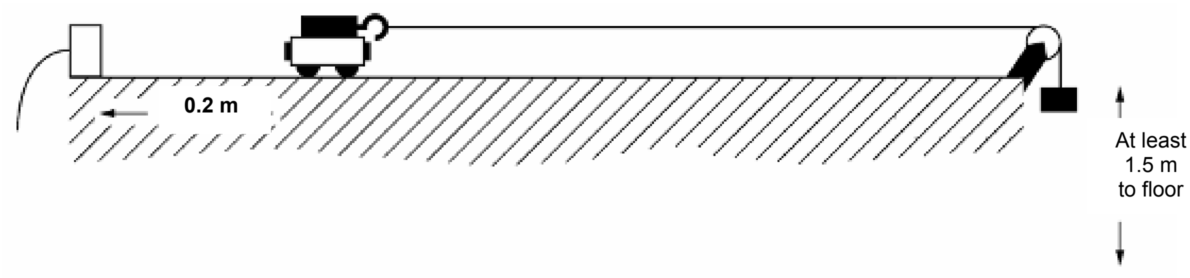
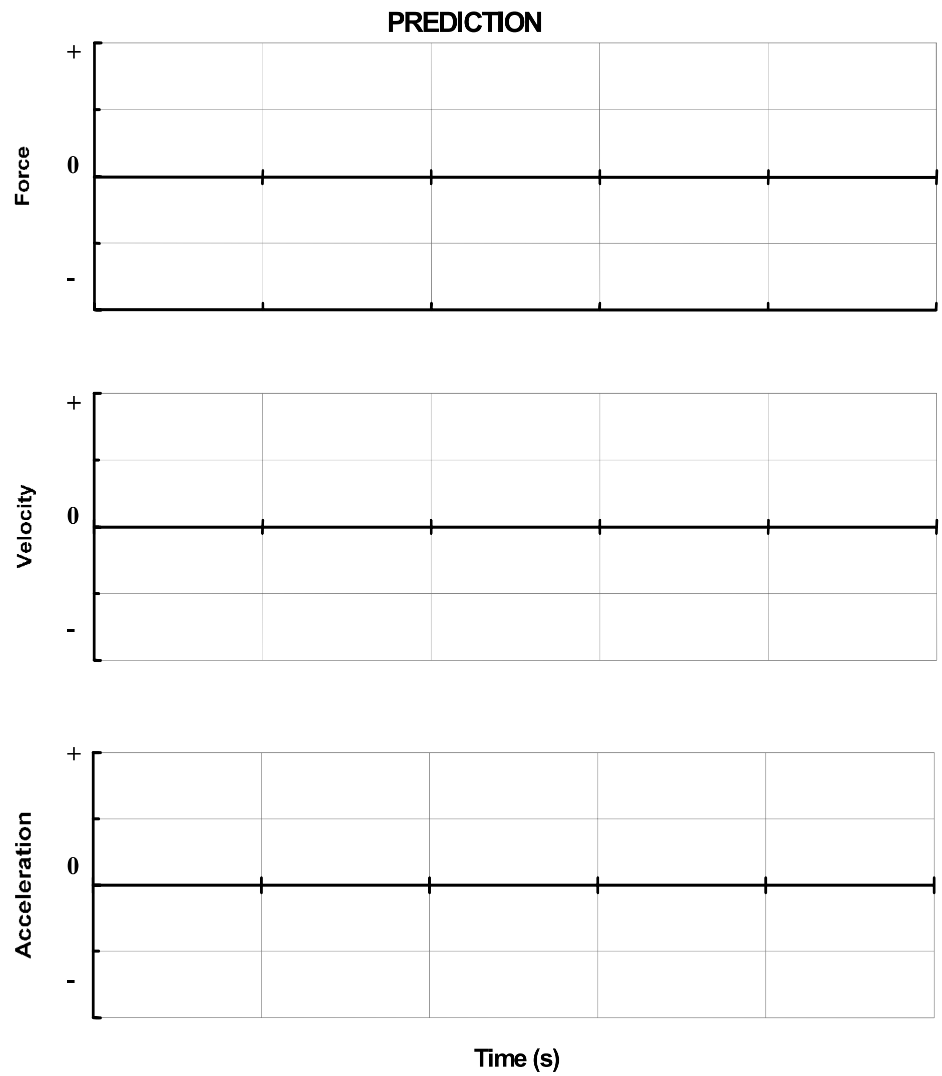
1. Set up the ramp, pulley, cart, string, motion detector, and force probe as shown below. The ramp should be level. The cart should be the same mass as before (about 1 kg).



Prediction 1-2: Suppose that you have a cart with very little friction and you pull this cart with a constant force. Sketch on the axes below the constant force and your predictions of the velocity—time and acceleration—time graphs of the cart's motion.



Be sure that the cart's friction is minimum. (If the cart has a friction pad, it should be raised so it doesn't contact the ramp.)

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2. Prepare to graph velocity, acceleration, and force. Open the experiment file called **Speeding Up Again L4.2-2** to display the velocity, acceleration, and force axes.

3. It is important to choose the amount of the falling mass so the cart doesn't move too fast to observe the motion. Experiment with different hanging masses (about 20 g) until you can get the cart to move across the ramp in about 4—5 s after the mass is released.

Record the total hanging mass that you decided to use: ______

Also test to be sure that the motion detector sees the cart during its complete motion.

4. **Zero** the force probe with the string hanging loosely so that no force is applied to the probe. **Zero** it again *before each graph.*

5. **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, and that it doesn't drag or pull the cart.*

Repeat until you get good graphs in which the cart is seen by the motion detector over its whole motion. Leave these data on the screen. Do not erase them.

6. If necessary, **adjust the axes** to display the graphs more clearly. **Print** out one set of graphs for your group and include them in your report. Do not erase your data; you will need it later.

Question 1-3: 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 1-4: How does the acceleration graph vary in time? Does this agree with your prediction? Does a constant applied force produce a constant acceleration?

Question 1-5: 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?

7. Accelerate the cart with a larger force than before. To produce a larger force, hang a mass about two times as large as in the previous activity.

Record the hanging mass: __________

8. Graph force, velocity, and acceleration as before. Keep your previous data and these data. You can choose to display or not display data under the data tab (with arrow). You can delete any other tries you make. *Don't forget to* ***zero*** *the force probe with nothing attached to the hook right before graphing*.

9. Use the **statistics feature** (Σ icon) of the software to measure the average force and average acceleration for the cart for the two sets of good data you have with different masses. Record your measured values in Table 2-1. *Find the mean values only during the time intervals when the force and acceleration are nearly constant*.

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Table 2-1

Hanging Mass (kg)	Average force (N)	Average acceleration (m/s^2)

Question 1-6: The average applied force increased because the gravitational force due to the hanging mass increased. Does there seem to be a simple mathematical relationship between the applied force and the average acceleration? Describe the relationship using an equation and using words.

Comment: The mathematical relationship that you have been examining between the acceleration of the cart and the applied force is known as *Newton's second law*.

INVESTIGATION 2: FORCE, MASS AND ACCELERATION

In previous activities you have applied forces to a cart having the same mass in each case and examined its motion. But when you apply a force to an object, you know that the object's mass has a significant effect on its acceleration. For example, compare the different accelerations that would result if you pushed a 1000-kg (metric ton) automobile and a 1-kg cart, with the same force!

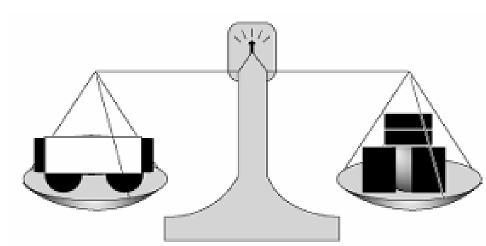
In this investigation you will explore the mathematical relationship between acceleration and mass when you apply the same constant force to carts of different mass. You will not need any additional materials.

Activity 2-1: Acceleration and Mass

You can easily change the mass of the cart by attaching masses to it, and you can apply the same force each time by using a string attached to appropriate hanging masses. By measuring the acceleration of different mass carts, you can find a mathematical relationship between the acceleration of the cart and its mass, when the force applied by the string is kept constant.

1. Set up the ramp, pulley, cart, string, motion detector, and force probe as shown in the figure below. Be sure that the ramp is level.

The force probe should be fastened securely to the cart. (*Be sure that the force probe does not extend beyond the end of the cart*. The cable must not interfere with the motion of the cart and must not be seen by the motion detector.)



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2. We will define a mass scale in which the unit is the mass of the cart (*including the force probe and flat brass piece*), called one *cart mass*. An equal arm balance can be used to assemble a combination of masses equal to *one cart mass*, although we will not use one. We will add the rectangular black masses that should each be 0.5 cart masses. You may also use an electronic balance to check, but it is limited to 600 g.

Assemble masses that you can add to the cart to make the cart's mass equal to 1.5, 2.0, 2.5, and 3.0 cart masses. The black rectangular masses should be 0.5 cart masses.

3. Now add enough masses to make the cart's mass 2.0 cart masses.

4. Be sure that the cart's friction is minimum. (If the cart has a friction pad, it should be raised so that it doesn't contact the ramp.)

5. Find a hanging mass (about 50 g) that will accelerate the cart across the track from left to right in about 4—5 s as it is falling.

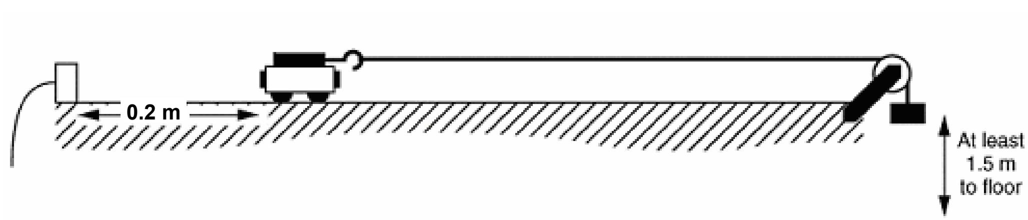
Record the value of this mass:_________

6. Open the experiment file called **Acceleration and Mass L4.4-1**.

7. As always, **zero** the force probe before each graph with nothing pulling on it. **Begin graphing**. Release the cart from rest when you hear the clicks of the motion detector.

Do not erase your data. You can hide it using the Data icon. **Print** out one set of graphs for your group report.

8. Use the mouse to highlight the time interval during which the acceleration is nearly constant on your graph (click and drag rectangle around region). Use the **statistics features** of the software to measure the average force experienced by the cart and average acceleration *during the same time interval*. Record your measured values for average force and average acceleration in the third row of Table 4-1 for 2.0 cart masses.



Be sure that the force probe body and cable do not extend beyond the back of the cart, and tape the cable back along the body to assure that the motion detector "sees" only the cart.

Table 4-1

Mass of cart(cart masses)	Average applied force (N)	Average acceleration (m/s^2)
1.0		
1.5		
2.0		
2.5		
3.0		

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9. Now we want to repeat your measurements with 1.0, 1.5, 2.5, and 3.0 cart masses. Do not yet start. Arrange the masses so you have 1.0 cart masses.

> **Comment:** You want to accelerate the cart with the *same applied force*. As you may have noticed, the force applied to the force probe by the string decreases once the cart is released. (You will explore why this is so in a later lab.) This decrease depends on the size of the acceleration. However, we do not want to change the hanging mass even if the applied force changes a little. It is approximately constant.

10. Before each measurement, **zero** the force probe with no force on it.

Graph the motion of the cart. (Don't forget to **zero** the force probe first.) Measure the average force and average acceleration of the cart *during the time interval when the force and acceleration are nearly constant* and record these values in the first row of Table 4-1.

11. Repeat for masses of 1.5, 2.5 and 3.0 cart masses.

Activity 2-2: Relationship Between Acceleration and Mass

1. Plot a graph of average acceleration vs. cart mass (with constant applied force). You can do this by opening the experiment file called **Avg.Accel. vs. Mass L4.4-3.** Enter the acceleration and mass data into the table on the screen. You may wish to **adjust the axes** to better display the data.

Question 2-1: Does the acceleration of the cart increase, decrease, or remain the same as the mass of the cart is increased?

> **Comment:** We are interested in the nature of the mathematical relationship between average acceleration and mass of the cart, with the applied force kept constant. As always, this can be determined from the graph by drawing a smooth curve which fits the plotted data points.

2. Use the fit routine in the software to fit the data on your graph of average acceleration vs. mass of the cart. Select various possible relationships and test them.

3. When you have found the best fit, **print** the graph along with the fit equation for your group report.

Question 2-2: What appears to be the mathematical relationship between acceleration and mass of the cart, when the applied force is kept constant?

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Question 2-3: If the combined force is $\sum\vec{\mathbf{F}}$, the cart mass is *M*, and the acceleration is $\vec{\mathbf{a}}$, write a mathematical relationship that relates these three physical quantities.

INVESTIGATION 3: TENSION AT BOTTOM OF PENDULUM SWING

1. Suspend the force probe from about 1 meter of string. Make sure there is some slack in the connecting cable.

2. Open the file called "Measuring force L4.1-2a"

3. With no tension in the string, zero the force probe, then let it hang motionless from the string. Begin graphing. You should observe a flat line, indicating the weight of the force probe. Notice that the force probe indicates a negative number, because the string is pulling on it. What will happen to the reading if the tension in the string increases? Test this by gently pulling downward on the force probe. Stop graphing. Clear all data.

4. If we let the force probe swing in a pendulum motion, what do you think will happen to the tension in the string at the moment the pendulum is at the bottom of its motion? Don't try it yet.

5. To answer this, we need to know the acceleration of the pendulum at the bottom of its motion. This is in the direction of the change in velocity. Imagine the pendulum is swinging from left to right. In what direction is the velocity just before it reaches the bottom? Draw a vector:

What about just after it passes the bottom? Draw a vector:

Now combine these to find the acceleration at the bottom:

In what direction is the acceleration at the bottom:

In what direction must the total force on the pendulum be at the bottom of its swing?

Knowing this, and that the weight of the pendulum is downward, how must the upward force (ie the tension in the string) compare to the weight of the pendulum, when at the bottom of its swing?

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6. Test this by hanging the force probe motionless, and graphing for a few seconds to show the weight of the pendulum. Stop graphing, but don't clear the data and pull the pendulum back about 30 degrees. Release and begin graphing. Stop after a few swings.

7. Print out a graph for your group. Indicate the different parts of the pendulum cycle. Was your prediction confirmed? Explain.

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