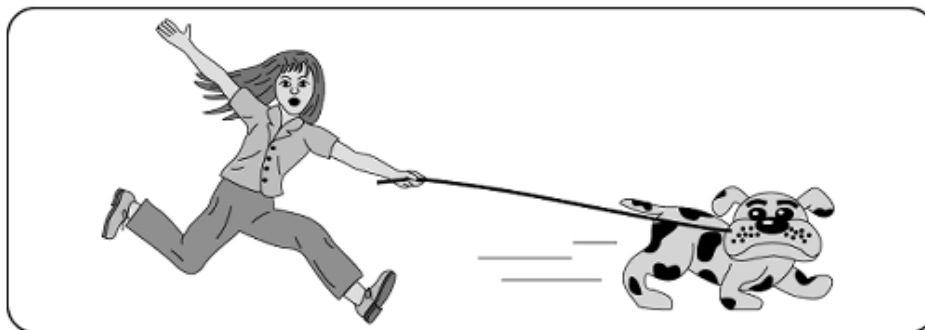


Name _____ Date _____ Partners _____

LAB 5: FORCE



A vulgar Mechanick can practice what he has been taught or seen done, but if he is in 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 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 *net force*. This net force is that which changes an object's motion according to *Newton's second law*.
- To examine the magnitude of the acceleration of a falling object under the influence of the gravitational force near the Earth's surface.
- To incorporate frictional forces into Newton's first and second laws of motion.
- To explore interaction forces between objects as described by *Newton's third law of motion*.
- To explore tension forces and understand their origin.

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.

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.

You will start your study of *Newtonian dynamics* by developing the concept of force. Initially, when asked to define forces, most people think of a *force* as *an obvious push or pull*, such as a punch to the jaw or the tug of a rubber band. By studying the acceleration that results from a force when little friction is present, we came up with a second definition of *force* as *that which causes acceleration*. These two alternative definitions of force do not always appear to be the same. Pushing on a wall doesn't seem to cause the wall to move. An object dropped close to the surface of the Earth accelerates and yet there is no visible push or pull on it.

The genius of Newton was to recognize that he could define *net force* or *combined force* as that which causes acceleration, and that if the obvious applied forces did not account for the degree of acceleration then there must be other “invisible” forces present. A prime example of an invisible force is the gravitational force – the attraction of the Earth for objects.



When an object falls close to the surface of the Earth, there is no obvious force being applied to it. Whatever is causing the object to move is invisible. It almost seems that we have to “invent” an invisible gravitational force to save Newton's second law. Since objects near the surface of the Earth fall with a constant acceleration, we will use *Newton's second law* to show that

there must be a constant (gravitational) force acting on the object.

Finding invisible forces (forces without an obvious agent to produce them) is often hard because some of them are not *active* forces. Rather, they are *passive* forces, such as *normal* forces, which crop up only in response to active ones. (In the case of normal forces, the active forces are ones like the push you exert on a wall or the gravitational pull on a book sitting on a table.)

Frictional and *tension* forces are other examples of passive forces. The passive nature of friction is obvious when you think of an object like a block being pulled along a rough surface. There is an applied force (active) in one direction and a frictional force in the other direction that opposes the motion. If the applied force is discontinued, the block will slow down to rest but it will not start moving in the opposite direction due to friction. This is because the frictional force is passive and stops acting as soon as the block comes to rest.

Likewise, tension forces, such as those exerted by a rope pulling on an object can exist only when there is an active force pulling on the other end of the rope.

After first learning how to measure force and its effect on motion, you will study vertical motion and the gravitational force. Then you will examine the motion of an object along an inclined ramp. You will use *Newton's laws of motion* as a working hypothesis to “invent” *frictional* and *tension* forces. We will examine *Newton's third law of motion* in a later lab.

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 previous 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 materials:

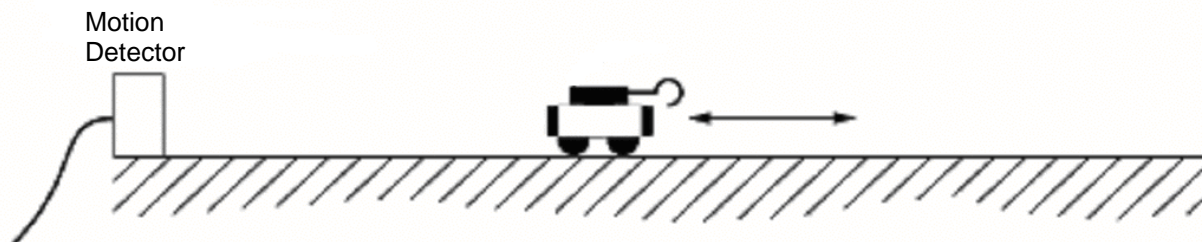
- motion detector
- motion cart
- rectangular brass piece to increase cart's mass to 1 kg
- rectangular 0.5 kg masses
- hanging masses
- 2-m motion track
- level
- low-friction pulley, lightweight string, table clamp
- electronic mass balance
- PASCO analog extension cable
- force probe with hook

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 net applied force and the velocity and acceleration, to see whether either is 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 piece (not the hanging masses) to place in the tray on top of the force probe to reach almost 1 kg total mass. Because the electronic mass balance only goes to 600 g, you will have to measure in two pieces and add. The total mass will be a little below 1 kg. Write the total mass below:

Total mass: _____



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.)

Note: The force probe must be “zeroed” or “tared” before each measurement. There is a small button on the side that you press to set the zero. The force is transmitted through the hook; **make sure you do this with nothing connected to the probe’s hook.**

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. **Do this before coming to lab.**

Test your predictions:

- Open the experiment file **L05.A1-1 Motion and Force**. This will set up velocity, force, and acceleration axes with a convenient time scale of 5 s. Check “Setup”.

Note: In this experiment you will cause the motion of the cart to change by grabbing the hook on the force probe. *Do not twist the hook! Be sure that the cart never gets closer than 20 cm to the motion detector.*

- Set the motion detector to narrow beam. **Zero** the force probe. Start the experiment with nothing moving. Make sure the acceleration and force are both zero.
- Zero** the force probe again; do it before every measurement. Grasp the force probe hook and **begin graphing**. When you hear the clicks, quickly pull the cart away from the motion detector and let go. Let the cart roll on its own for a second or two, then quickly stop it by grabbing the hook. Use the hook to move the cart back and forth a few times; this allows you to measure the force on the cart. *Keep your hand out of the motion detector’s beam!*

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

Question 1-1: 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.

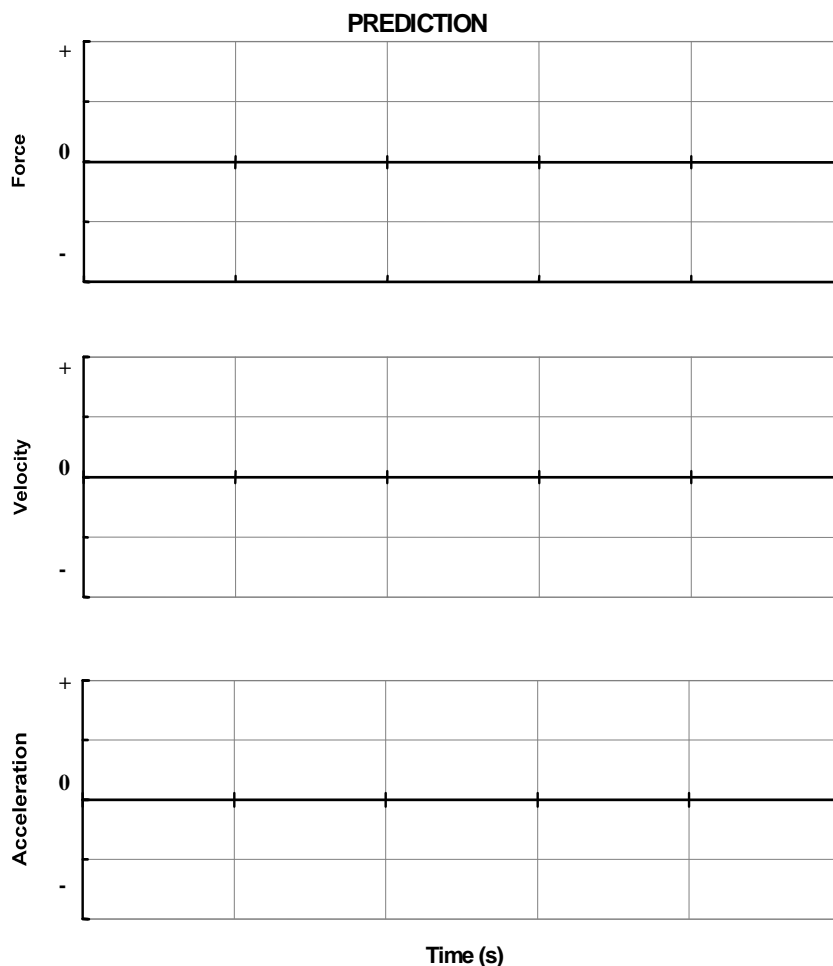
ACTIVITY 1-2: SPEEDING UP AGAIN

You have seen in the previous activity that force and acceleration seem to be related. Now we will examine the relationship between force and acceleration more carefully.



1. Set up the track, pulley, cart, string, motion detector, and force probe as shown above. The track should be level on the table. The cart should be the same mass as before (about 1 kg). Make 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.

Prediction 1-2: Suppose that you have a cart with very little friction and you pull the 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. **Do this before coming to lab.**



2. Prepare to graph velocity, acceleration, and force. Open the experiment file called **L05.A1-2 Speeding Up Again** 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 (try 20 g) until you can get the cart to move across the track in about 4-5 s after the mass is released. Also test to be sure that the motion detector sees the cart during its complete motion.

Record the total hanging mass that you decide to use: _____

4. **Zero** the force probe with the string hanging loosely so that no force is applied to the probe. **Zero** it again *before each experiment*.
5. **Start taking data.** 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. Do not erase your data; you will need it later.

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

Question 1-4: 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 total 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 (click-and-drag a rectangle to select a region). Record your measured values in Table 5-1. *Find the mean values only during the time intervals when the force and acceleration are nearly constant.*

10. **Print** out one set of graphs with all data and mean values showing for your group and include them in your report.

Table 5-1

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

Question 1-5: 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 then again using words.

Question 1-6: Did you find that the acceleration increased in the same ratio as the hanging mass did? Should it do so? Explain.

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: MOTION AND GRAVITY

Let's begin the study of the phenomenon of gravity by examining the motion of an object such as a ball when it is allowed to fall vertically near the surface of the Earth. This study is not easy, because the motion happens very quickly! You can first predict what kind of motion the ball undergoes by tossing a ball in the laboratory several times and seeing what you think is going on.

A falling motion is too fast to observe carefully by eye. You will need the aid of the motion detector and computer to examine the motion quantitatively. Fortunately, the motion detector can do measurements just



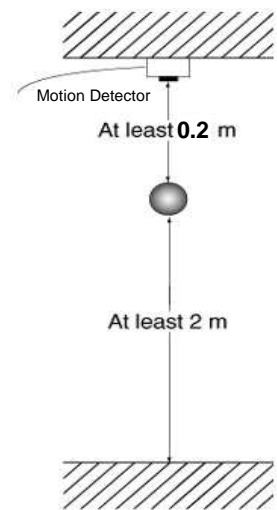
fast enough to graph this motion. To carry out your measurements you will need

- motion detector
- basketball
- table clamps, rods, etc.
- 3 m tape measure

ACTIVITY 2-1: MOTION OF A FALLING BALL

You will use the motion detector to examine the motion of a falling ball. The easiest way is to mount the motion detector as high up as you can and to use a large ball that is not too light (like a basketball rather than a beach ball). It is essential to keep your hands and the rest of your body out of the way of the motion detector after the ball is released. This will be difficult and may take a number of tries. It also will take some care to identify which portions of your graphs correspond to the actual downward motion of the ball and which portions are irrelevant. We will take data at a higher rate than we did previously while walking in front of the motion detector.

1. Use the table clamps, rods, and right angle devices to attach the motion detector, about 2 m above the floor, with the detector looking straight downward, as shown on the right. Mount the detector so it does not see much of the table or apparatus on the table. Think about where to mount it. The motion detector switch should be on broad beam.
2. Open the experiment file called **L05.A2-1 Falling Ball**. This experiment file will also set the data collection to a faster rate than has been used before (50 points/s). Because the motion detector is pointing downward – in the negative y direction – the software has been set up to make **distance away from the detector negative**.
3. Hold the ball at least 20 cm directly below the motion detector and at least 1.8 m above the floor. *Remember that your hands and body must be completely out of the path of the falling ball, so the detector will see the ball – and not your hands or body – the whole way down.*
4. When everything is ready, **start** the experiment and release the ball as soon as you hear the clicks from the motion detector. Let the ball hit the floor and then stop the experiment.
5. **Adjust the axes** if necessary to display the velocity and acceleration as clearly as possible. Do not erase the data so that the graphs can be later used for comparison. You can repeat the run without erasing the data if you choose; each run will have a different run number.



As you saw in a previous lab, you can find a value for the average acceleration in various ways. One method is to read the average value from the acceleration - time graph. Another is to find the slope of the velocity-time graph.

6. Use the acceleration-time graph to determine the average value of the acceleration during the time interval from just after the ball began falling (beginning of uniform acceleration) to just before the ball stopped falling (end of uniform acceleration).

Average acceleration: _____ σ _____

7. Use the **fit routine** to find the mathematical relationship between velocity and time during the same time interval as in step 1. Write below the equation you find from the fit that relates velocity (v) to time (t).

8. From the equation in the previous step, what is the value of the acceleration?

Average acceleration: _____ σ _____

9. **Print** one set of graphs from step 7 for your group and include them with your report. Make sure the highlighted region and the fit results are shown on the printed graph.

Question 2-1: Did the two values for the gravitational acceleration agree within the uncertainties? Should they agree with each other? Explain.

ACTIVITY 2-2: MOTION UP AND DOWN

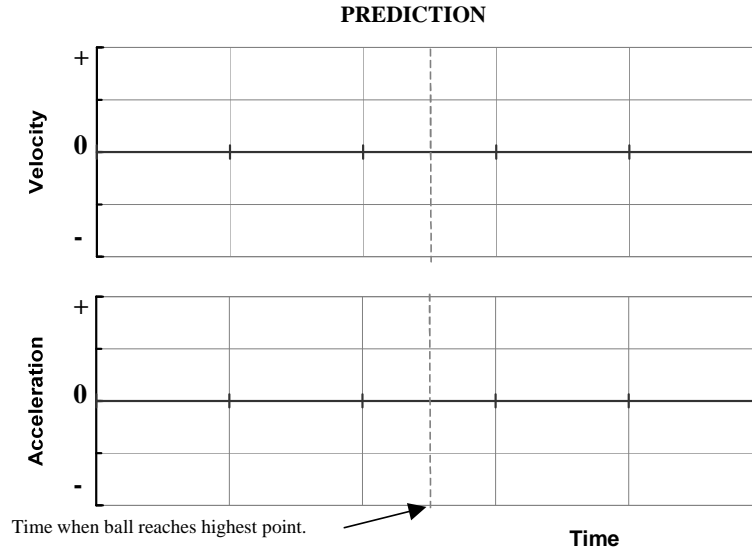
Prediction 2-1: Suppose that you toss a ball upward and analyze the motion as it moves up, reaches its highest point, and falls back down. Take the direction up as positive. Is the velocity +, -, or 0? Is the **acceleration** of the ball the same or different during the three parts of the motion – moving upward, momentarily at the highest point, and moving downward? Discuss the velocity and acceleration in each case below. **Do this before coming to lab.**

Moving upward:

Momentarily at highest point:

Moving downward:

Prediction 2-2: Sketch on the axes below your predictions of the velocity - time and acceleration - time graphs for the entire motion of the ball from the moment it leaves your hand going up until just before it returns to your hand. Assume that the positive direction is upward.



Throwing the ball upward and keeping it in the range of the motion detector is harder to do than dropping the ball. Try to throw the ball up directly under the motion detector. It may take a number of tries. *Again be sure that your body is not seen by the motion detector.*

1. The same experiment file **L05.A2-1 Falling Ball** used in Activity 2-1 should work in this activity as well. You can keep the graphs from Activity 2-1 on the screen if you desire. The new data will be in a different color. You can also click on the Data icon and choose not to display a particular data run.
2. When everything is ready, **begin graphing**, and when you hear the clicking begin, toss the ball up toward the motion detector. Toss the ball as high as you can, but remember that it should never get closer than 20 cm below the motion detector. A short quick throw will work best.

Repeat until you get a throw where you are sure the ball went straight up and down directly below the detector. You can choose under Experiment to delete the last data run if you do not want to keep it. You can also “click” on a graph and use the DELETE key to remove it. You may need to make several tries before you decide to keep the data. Let all group members try, if you have time.

3. When you obtain a good run, **print** one set of graphs for your group and include them in your report.
4. Label the portions of the printed graphs that show the ball’s up and down motion. Also label with an arrow the instant in time when the ball reached its highest point.

Question 2-2: Compare the experimental graphs to your predictions. In what ways do they differ, and in what ways are they the same? Qualitatively compare the acceleration during the three parts of the motion – on the way up after it leaves your hand, at the highest point, and on the way down. Explain your observations based on the sign of the change in velocity. (See Predictions 2-1 and 2-2.)

On the way up:

At the highest point:

On the way down:

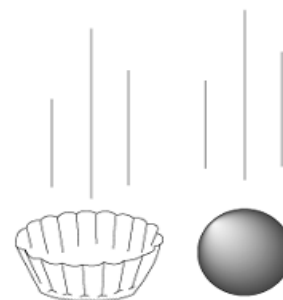
Question 2-3: There is a common idea that the acceleration of the ball must be zero when it stops at the top. If this were true, could the velocity of the ball change if the acceleration is zero? Explain.

ACTIVITY 2-3: VERTICAL MOTION WITH AIR RESISTANCE

In this Activity you will use the motion detector to examine the motion of a paper coffee filter falling from rest. In addition to the setup in Activity 2-1 you will need

- a flat-bottomed paper coffee filter - the type with folds along the sides

1. Use the experiment file **L05.A2-3 Falling Filter**. As usual, wait until you hear the motion detector click and then release the coffee filter with the flat bottom facing down as shown on the left. If necessary, increase the time range to record the complete motion of the filter and **adjust the velocity and acceleration axes** if necessary to display the graphs more clearly. It may take you several tries to obtain a good graph, because the coffee filter tends to float to the side out of range of the motion detector.



2. Be sure to keep your body out of the way of the motion detector.
3. **Print** out one set of graphs and include them with your report.

Question 2-4: Compare the graphs to those for the falling ball. Does the filter also appear to fall with a constant acceleration? If not, how would you describe the motion? Is the velocity changing as the filter falls? If so, how?

Question 2-5: Based on *Newton's laws of motion*, do you think that the gravitational force is the only force acting on the filter? If there is another force, what is its direction and how does its magnitude compare to the gravitational force? Explain.

INVESTIGATION 3: NEWTON'S LAWS WHEN FRICTION IS PRESENT

In previous labs we have worked hard to create situations where we could ignore the effects of friction. We have concentrated on *applied* forces involving pushes and pulls that we can see and measure directly. The time has come to take friction into account. You can make observations by applying a force directly to your force probe mounted on a block (with significant friction) and comparing the block's acceleration to the acceleration of the cart (with negligible friction).

To make observations on the effects of friction you will need

- force probe
- motion detector
- string
- 2-m motion track
- wood friction block

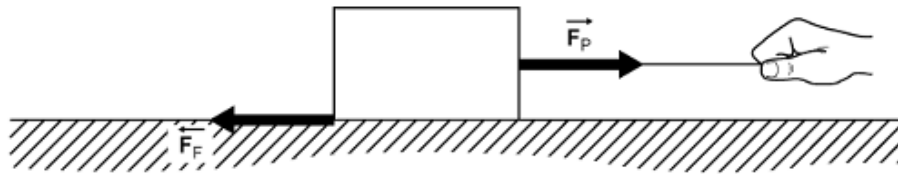
ACTIVITY 3-1: STATIC AND KINETIC FRICTIONAL FORCES

If the frictional force is equal in magnitude to the applied force, then according to Newton's first law, the block must either remain at rest or move with a constant velocity.

The frictional forces when two objects are sliding along each other are called *kinetic* frictional forces. If the objects are not sliding along each other, then the frictional forces

are called *static* frictional forces. In this Activity you will examine whether the frictional force is different when an object is at rest (*static* friction) than when it is sliding along a track (*kinetic* friction).

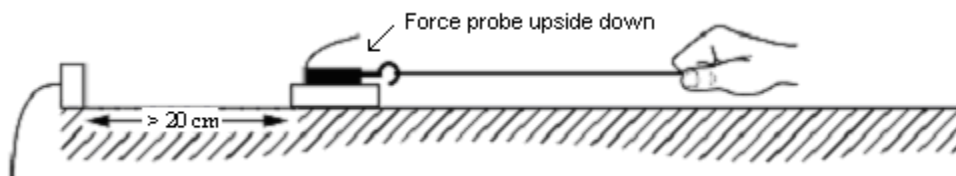
Prediction 3-1: A block is sitting on a table, as shown below. You pull on a string attached to the block, but the block doesn't move because the frictional force opposes your pull. You pull harder, and eventually the block begins to slide along the table top. From what you have learned previously (textbook, lecture, etc.) how should the frictional force *just before* the block started sliding compare to the frictional force when the block is actually sliding? Explain.



Prediction and explanation:

You can test your prediction by mounting the force probe on a wooden block and pulling the block along the table, not on the motion track.

1. Set up the block, string, force probe, and motion detector as shown below. Set the force probe upside down on top of the friction block which fits inside the force probe tray. **The wooden side of the friction block should be down on the table, not on the track.** You will be adding 0.5 kg (black rectangular) masses (not the hanging masses) to the top of the force probe. Start with adding one 0.5 kg mass to the force probe to make the overall mass $M \approx 1$ kg. Remove the motion detector from the track and place it on the table. The narrow beam of the motion detector seems to work best.



2. Measure and record the total mass of the block and other components: _____ kg. You may have to measure them separately on the digital mass scale and add them. Enter the mass into Table 5-2.
3. Prepare to graph velocity and force by opening the experiment file called **L05.A3-1 Static and Kinetic Friction**.
4. **Zero** the force probe with nothing pulling on it. Make sure 0.5 kg mass is on top of the force probe. It should rest there okay without tape, but you can tape it if needed. **Begin graphing** with the string loose, then gradually pull *very gently* on the force probe with the string and increase the force very slowly. *Be sure that you pull horizontally – not at an angle up or down.* When the block begins to move, pull only hard enough to keep it moving with a small velocity, which is as constant (steady) as possible.
5. **Do not erase your data** so that you can use them for comparison with those in Activity 3-2. Do not yet print out the data.

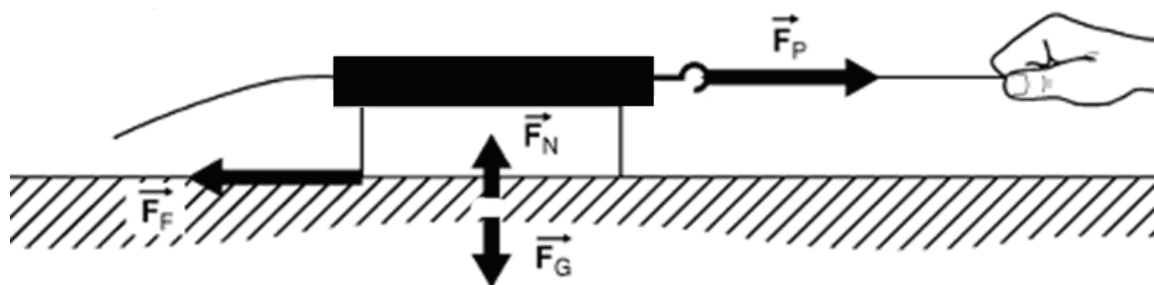
Question 3-1: Does the block feel a force on it due to the string even though the block is not moving? Why? What happens to the frictional force *just as* the block begins to slide? Does this agree with your prediction? Explain.

ACTIVITY 3-2: FRICTIONAL FORCE AND NORMAL FORCE

The frictional force is nearly the same regardless of how fast the object moves, but there is usually a difference between *static* and *kinetic* frictional forces. Now you will examine if frictional forces depend on the force between the surface and the object – the *normal* force.

Comment: All of the forces exerted on a block being pulled on a table top or ramp are shown in the diagram below. As you know, surfaces like a wall or a table top can exert a force perpendicular to the surface called a *normal* force. In the case of the block on the table, the table exerts a *normal* force upward on the block, and the Earth exerts a *gravitational* force (the weight of the block) downward on the block.

Since you know that the block doesn't move up or down as it sits at rest or slides along the table's surface, the combined (net) vertical force must be zero according to *Newton's first law*. So the magnitude of the normal force must just equal the magnitude of the gravitational force.



If we use the symbols from the diagram above, we obtain

$$F_G = F_N = mg$$

where m is the total mass of the object, and g is the gravitational acceleration, 9.8 m/s^2 .

Prediction 3-2: If you increase the normal force exerted by the table on the block (by adding extra masses to the force probe), what will happen to the frictional force? Explain.

1. Test your prediction. Use the same setup and experiment file, **L05.A3-1 Static and Kinetic Friction**, as in Activity 3-1.
2. Place three additional $\frac{1}{2}$ kg masses on top of the force probe for a total of four $\frac{1}{2}$ kg masses. Enter the total mass into Table 5-2.
3. **Zero** the force probe with nothing pulling on it. The data from the previous Activity 3-1 is still being displayed on the computer screen. As in Activity 3-1, **begin graphing** with the string loose, then gradually pull *very gently* on the force probe with the string, and increase the force very slowly. *Be sure that you pull horizontally—not at an angle up or down.* When the block begins to move, pull only hard enough to keep it moving with a small velocity that is as constant (steady) as possible. You should see a difference between static and kinetic friction.
4. Both sets of data with different masses should be displayed. **Print** out these data and carefully mark on your graph the total mass for each set of data.

Question 3-2: Compare the two sets of graphs. In what ways are they similar, and in what ways are they different? Are the kinetic frictional forces the same or different? Explain.

5. Use the statistics features of the software to measure the average frictional forces for both sets of data during the time when the objects were moving at a constant speed. You can choose which Run # you are displaying by clicking on and off the Run # under the Data icon. Record the frictional forces in the appropriate row and column in Table 5-2. Fill in all the other information needed in Table 5-2

Table 5-2

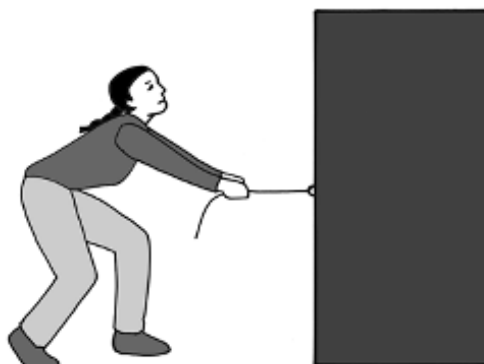
Block, force probe and mass	Total Mass (kg)	Normal Force (N)	Average kinetic frictional force (N)	Coefficient of friction
With one 0.5 kg mass				
With four 0.5 kg masses				

Question 3-3: Does the relationship $F_{friction} = \mu F_{normal}$ (where μ is a constant called the *coefficient of friction*) seem plausible? Was the coefficient of friction constant? Discuss.

INVESTIGATION 4: TENSION FORCES

When you pull on a rope attached to a crate, your pull is somehow transmitted down the rope to the crate. *Tension* is the name given to forces transmitted along stretched strings, ropes, rubber bands, springs, and wires.

Is the whole force you apply transmitted to the crate, or is the pull at the other end larger or smaller? Does it matter how long the rope is? *How* is the force “magically” transmitted along the rope? These are some of the questions you will examine in this investigation.



Obviously, the rope by itself is unable to exert a force on the crate if you are not pulling on the other end. Thus, tension forces are *passive* just like *frictional* and *normal* forces. They act only in response to an active force like your pull.

Before you begin, examine your knowledge of tension forces by making the following predictions.

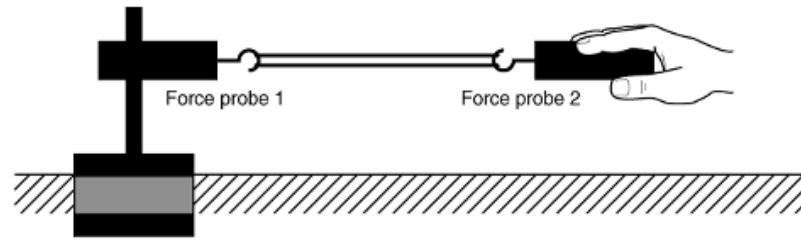
Prediction 4-1: If you apply a force to the end of a rope as in the picture above, is the whole force transmitted to the crate, or is the force at the crate smaller or larger than your pull?

To test your prediction you will need the following in addition to what you already have:

- table clamp and rod
- short piece of string

ACTIVITY 4-1: MECHANISM OF TENSION FORCES

1. Open the experiment file called **L05.A4-1 Tension Forces**.
2. Attach force probe 1 horizontally to the table clamp and rod so that it won't move when pulled. See the figure below.
3. Place a string between the force probes.
4. **Zero** both force probes with the string hanging loosely. **Begin graphing**, and pull softly at first on force probe 2, then harder, and then vary the applied force. *Be sure not to exceed 50 N.*



5. **Print** out one set of graphs for your group.

Question 4-1: Based on the readings of the two force probes, when you pull on one end of the string, is the force transmitted down to the other end? Explain.

6. Indicate with arrows on the diagram above the directions of the forces exerted by the string on force probe 1 and on force probe 2.

