Name___________________________ **Date**________________

PRE-LAB PREPARATION SHEET FOR Lab 9: WORK AND ENERGY

(Due at the beginning of Lab 9)

Directions:
Read over Lab 6 and then answer the following questions about the procedures.

1. What is your Prediction 1-1? Which job would you choose? Why?

2. In Activity 1-2, why are you asked to pull both parallel to the plane and at a 45° angle to the plane?

3. What is the definition of power?

4. How will you find the work done by the spring force in Activity 2-2?

5. How will work done and change in kinetic energy be compared in Activity 3-3?

Name______________ Date____________________ Partners______________

LAB 9: WORK AND ENERGY

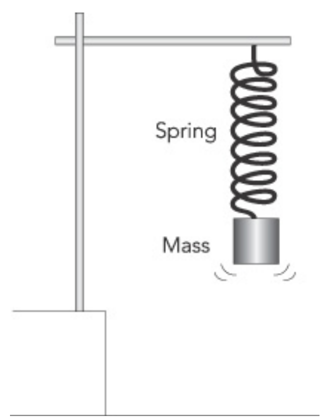
Energy is the only life and is from the Body; and Reason is the bound or outward circumference of energy. Energy is eternal delight.

—William Blake

OBJECTIVES

- To extend the intuitive notion of work as physical effort to a formal mathematical definition of work, W, as a function of both the force on an object and its displacement.
- To develop an understanding of how the work done on an object by a force can be measured.
- To understand the concept of power as the rate at which work is done.
- To understand the concept of kinetic energy and its relationship to the net work done on an object as embodied in the *work–energy principle*.

OVERVIEW



In your study of momentum, you saw that while momentum is always conserved in collisions, apparently different outcomes are possible. For example, if two identical carts moving at the same speed collide head-on and stick together, they both end up at rest immediately after the collision. If they bounce off each other instead, not only do both carts move apart at the same speed but in some cases they can move at the same speed they had coming into the collision. A third possibility is that the two carts can "explode" as a result of springs being released (or explosives!) and move faster after the interaction than before.

Two new concepts are useful in further studying various types of physical interactions—*work* and *energy*. In this lab, you will begin the process of understanding the scientific definitions of *work* and *energy,* which in some cases are different from the way these words are used in everyday language.

You will begin by comparing your intuitive, everyday understanding of work to its formal mathematical definition. You will first consider the work done on a small point-like object by a constant force. There are, however, many cases where the force is not constant. For example, the force exerted by a spring increases the more you stretch the spring. In this lab you will learn how to measure and calculate the work done by any force that acts on a moving object (even a force that changes with time).

Often it is useful to know both the total amount of work that is done, and also the rate at which it is done. The rate at which work is done is known as the *power.*

Energy is a powerful and useful concept in all the sciences. It is one of the more challenging concepts to understand. You will begin the study of energy in this lab by considering *kinetic energy*—a type of energy that depends on the velocity of an object and on its mass.

By comparing the change of an object's kinetic energy to the net work done on it, it is possible to understand the relationship between these two quantities in idealized situations. This relationship is known as the *work–energy principle.*

You will study a cart being pulled by the force applied by a spring. How much net work is done on the cart? What is the kinetic energy change of the cart? How is the change in kinetic energy related to the net work done on the cart by the spring?

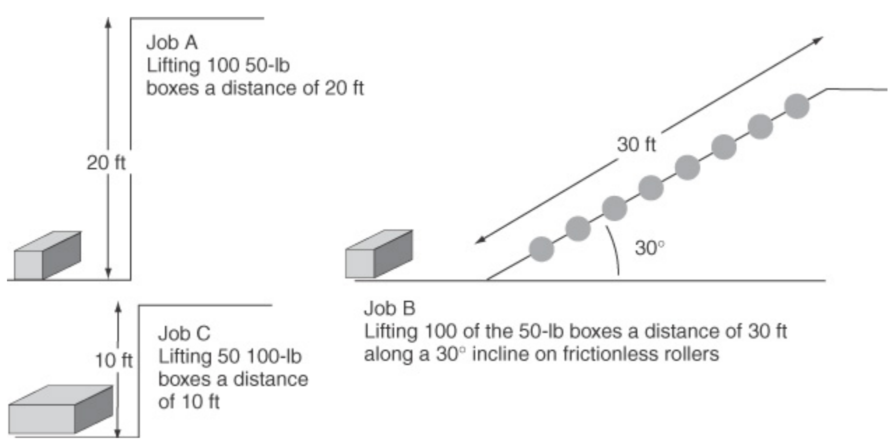
INVESTIGATION 1: THE CONCEPTS OF PHYSICAL WORK AND POWER

While you all have an everyday understanding of the word "work" as being related to expending effort, the actual physical definition is very precise, and there are situations where this precise scientific definition does not agree with the everyday use of the word.

You will begin by looking at how to calculate the work done by constant forces, and then move on to consider forces that change with time.

Let's begin with a prediction that considers choosing among potential "real-life" jobs.

Prediction 1-1: Suppose you are president of the Load 'n' Go Company. A local college has three jobs it needs to have done and it will allow your company to choose one before offering the other two jobs to rival companies. All three jobs pay the same total amount of money.



Which one would you choose for your crew? Explain why.

The following activities should help you to see whether your choice makes the most sense. You will need the following:

- IOLab
- two heavy books of approximately the same weight
- smooth board or other level surface at least 0.5 m long that can be inclined
- meter stick or measuring tape
- string
- protractor

Activity 1-1: Effort and Work—Calculating Work

1. Lift one of the books at a slow, constant speed from the floor to a height of about 1 m. Repeat several times. Note the effort that is required.

Repeat, this time lifting the two books 1 m.

2. Push a book 1 m along the floor at a constant speed. Repeat several times.

Repeat, this time piling two books on top of each other and pushing them 1 m.

Question 1-1: In each case, lifting or pushing, why must you exert a force to move the object?

Question 1-2: How much more effort does it take to lift or push two books instead of one?

3. Lift a book with your hands at a slow, constant speed from the floor to a height of about 1 m. Repeat, this time lifting the book a distance of 2 m.

4. Push a book 1 m along the floor at a constant speed. Repeat, this time pushing the book a distance of 2 m.

Question 1-3: How much more effort does it take to lift or push an object twice the distance?

Question 1-4: If work were defined as "effort," how would you say work depends on the force applied and on the distance moved?

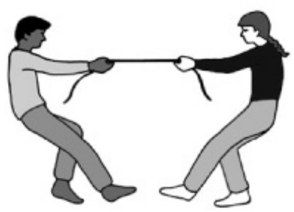
In physics, work is not simply effort. In fact, the physicist's definition of work is precise and mathematical. To have a full understanding of how work is defined in physics, we need to consider its definition for a very simple situation and then enrich it later to include more realistic situations.

Note: All of the definitions of work in this unit apply only to very simple objects that can be idealized as point masses or are essentially rigid objects that don't deform appreciably when acted on by a force. The reason for limiting the definition to such objects is to avoid considering forces that cause the shape of an object to change or cause it to spin instead of changing the velocity or position of its center of mass.

If a rigid object or point mass experiences a constant force along the same line as its motion, the *work* done by that force is defined as the product of the force and the displacement of the center of mass of the object. Thus, in this simple situation where the force and displacement lie along the same line

$$W = F_x \, \Delta x$$

where W represents the work done by the force, F_x is the force, and Δx is the displacement of the center of mass of the object along the x axis. Note that if the force and displacement (direction of motion) are in the same direction (i.e., both positive or both negative), the *work done by the force is positive.* On the other hand, a force acting in a direction opposite to displacement does *negative work.* For example, an opposing force that is acting to slow down a moving object is doing *negative work.*



Question 1-5: Does this definition of work agree with the amount of effort you had to expend when you moved books under different conditions? Explain.

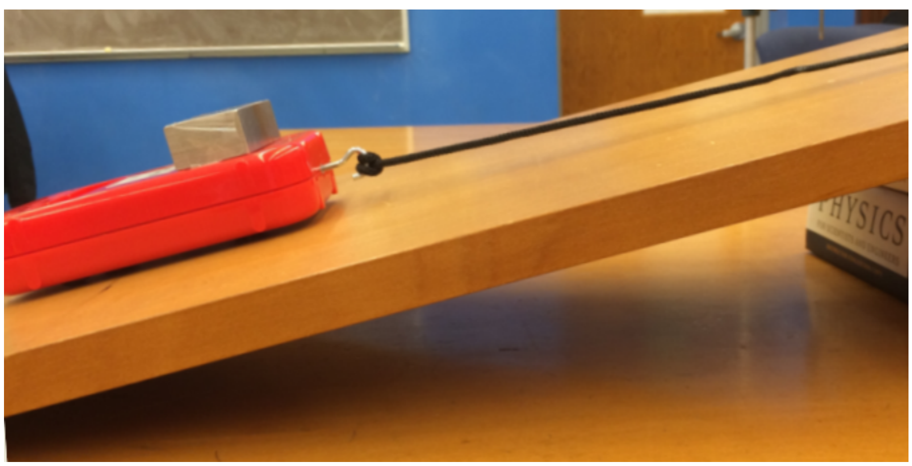
Question 1-6: Does effort necessarily result in physical work? Suppose two people are in an evenly matched tug of war. They are obviously expending *effort* to pull on the rope, but according to the definition are they doing any *physical work* as defined above? Explain.

Activity 1-2: Calculating Work When the Force and Displacement Lie Along the Same Line and When They Don't

In this activity, you will use the IOLab to measure the force needed to pull the IOLab, on its wheels, up the inclined smooth board (or other level surface). You will examine two situations. First you will exert a force parallel to the surface of the ramp, and then you will exert a force at an angle to the ramp. You will then be able to see how to calculate the work when the force and displacement are not in the same direction in such a way that the result makes physical sense.

1. Open the IOLab software and under Sensors, choose the "Force" and "Wheel" (select the Displacement and the Velocity) as items to be measured. Calibrate the IOLab force sensor if it has not already been calibrated. Click the Reverse y-axis boxes. (Remember that this just sets the +y direction as positive.)

2. Set up the IOLab and ramp as shown in the diagram below. Attach a short string (about 50 cm) to the eyebolt screwed into the force sensor of the IOLab. Put one of the books on the IOLab. Taping the book or another object about the mass of the IOLab over the single wheel will prevent the IOLab from flipping over. Support one end of the ramp so that it is inclined to an angle of about 15–20°. Use the protractor or calculate to make sure you have an angle of at least 15°.



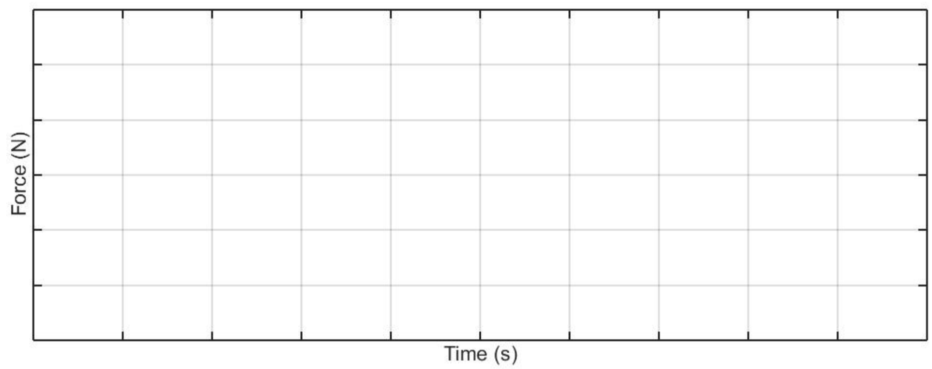
Reminder: It is important to zero the Force Sensor on the IOLab with nothing pushing or pulling on the eyebolt just before making measurements, so not on the ramp.

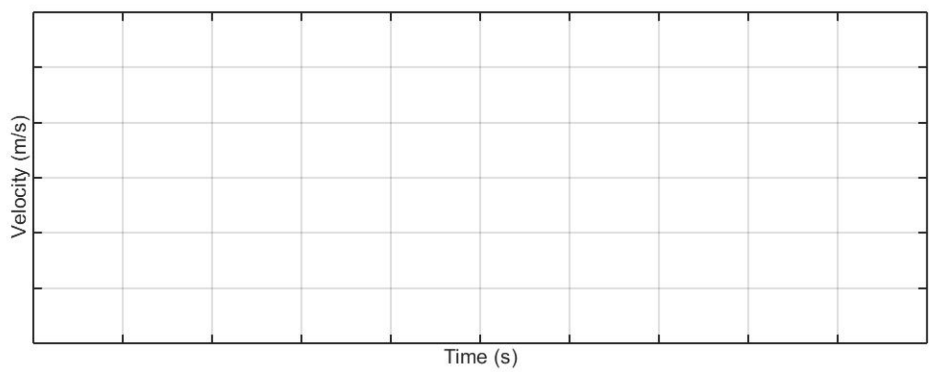
3. Find the force needed to pull the IOLab and book up the ramp at a constant velocity. Begin graphing force vs. time and the displacement as a function of time as you pull the IOLab and book up the ramp slowly *at a constant velocity.* Pull the IOLab so that the string is always *parallel to the ramp.* Pull the IOLab and book a measured distance along the ramp, say 0.5 m.

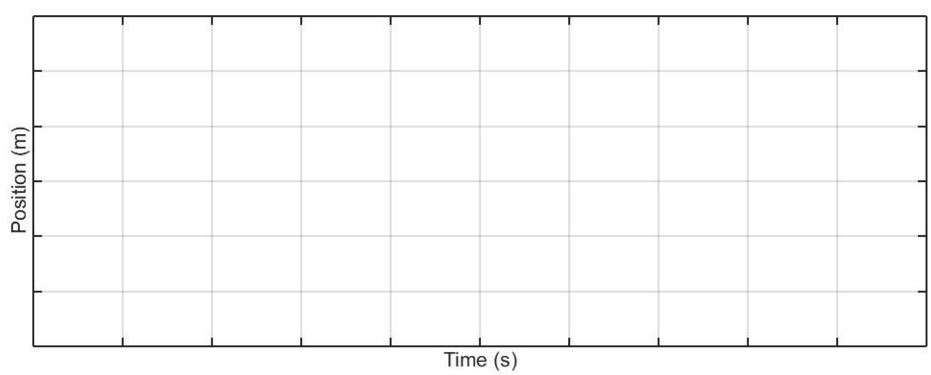
4. Print or save your graphs, and sketch them on the axes below.

5. Use a time interval over which the force is relatively constant and record the average force and the displacement. Using the software, find the average (mean) force applied to the IOLab and book during the time interval when the IOLab was moving with a constant velocity. Make sure it was really moving at nearly a constant velocity. Do not include the force to get the cart moving.

Average force in the *y* direction pulling parallel to surface:______N







Prediction 1-2: Suppose that the force is not exerted along the line of motion but is in some other direction. If you try to pull the IOLab up along the same ramp in the same way as before (again with a constant velocity), only this time with a force that is not parallel to the surface of the ramp, will the force sensor measure the same force, a larger force, or a smaller force? Note that, the force sensor measures the force only in the ***y*-direction**.

Now test your prediction by measuring the force needed to pull the cart and mass up along the ramp at a constant velocity, pulling at an angle of 45° to the surface of the ramp. To prevent the IOLab from flipping over backwards, be sure that the book is taped centered to the front of the IOLab, over the single wheel..

6. Attach the string to the eyebolt as before. Measure the 45° angle with a protractor. Begin graphing the force and the velocity and position as you pull the IOLab up *at a slow constant speed* as shown in the picture above. *Be sure the IOLab does not lift off the surface of the ramp.*

7. Print or save your graphs, and sketch them on the previous axes.

8. Use a time interval over which the force is relatively constant and record the average force and the displacement. Using the software find the average (mean) force applied to the IOLab and book in both cases during the time interval when the IOLab was moving with a constant velocity. Make sure it was really moving at a nearly constant velocity. Do not include the force to get the cart moving.

Average force in the *y* direction pulling at 45° to the surface:______N

Question 1-7: Did it seem to take more "effort" to move the IOLab and mass when the force was inclined at an angle to the ramp's surface? Do you think that more physical work was done to move the IOLab and mass over the same distance at the same slow constant speed?

It is the force component parallel to the displacement that is included in the calculation of work. Thus, when the force and displacement are not parallel, the work is calculated by

$$W = F_x \, \Delta x = \left(F \cos\theta\right) \Delta x$$

Question 1-8: Do your observations support this equation as a reasonable way to calculate the work? Explain.

Question 1-9: Based on all of your observations in this investigation, was your choice in Prediction 1-1 the best one? In other words, did you pick the job requiring the least physical work? Explain.

Sometimes more than just the total physical work done is of interest. Often what is more important is the rate at which physical work is done. Average power, <*P*>, is defined as the ratio of the amount of work done, ΔW, to the time interval, Δt, in which it is done, so that

$$< P >= \frac{\Delta W}{\Delta t}$$

If work is measured in joules and time in seconds, then the fundamental unit of power is the joule/second, and one joule/second is defined as one **watt**.

A more traditional unit of power is the horsepower, which originally represented the rate at which a typical work horse could do physical work. We now define the equivalency between one horsepower and watts as follows:

1 horsepower (or hp) = 746 watts

Cars are often identified by how much power they can produce. For example, a typical car engine has a peak power of 175 hp. How many horsepower do you think you could deliver on a bicycle? How much can a top athlete deliver?

INVESTIGATION 2: WORK DONE BY CONSTANT AND NONCONSTANT FORCES

Many forces in nature are not constant. A good example is the force exerted by a spring as you stretch it. In this investigation you will see how to calculate work and power when a non-constant force acts on an object.

You will start by looking at a somewhat different way of calculating the work done by a constant force by using the area under a graph of force vs. position. It turns out that, unlike the equations we have written down so far, which are only valid for constant forces, the method of finding the area under the graph will work for both constant and changing forces.

You will need the following:

- IOLab
- smooth board or other level surface at least 0.5 m long
- meter stick or measuring tape
- spring, un-stretched length about 7 cm

Activity 2-1: Work Done by a Constant Lifting Force

In this activity you will measure the work done when you lift an object from the floor through a measured distance. You will use the force sensor to measure the force and the wheel to measure distance.

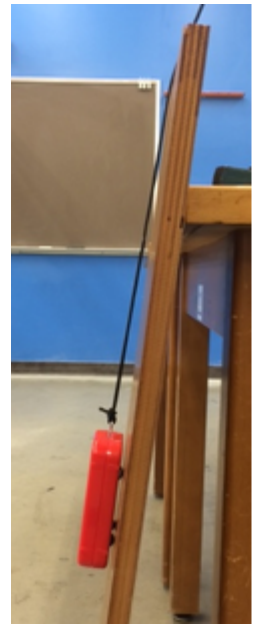
1. Lift the IOLab by the string which is attached to the eyebolt screwed into the force sensor.

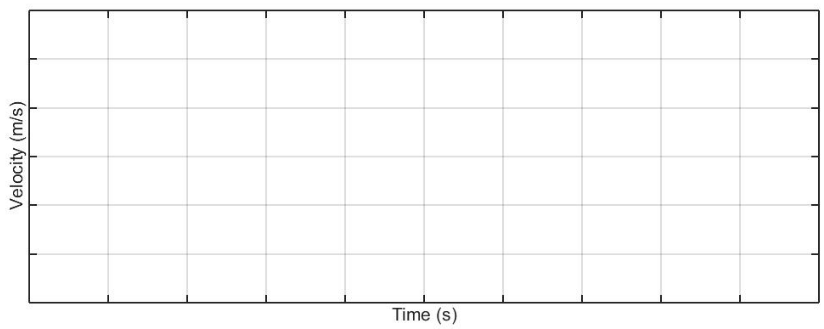
2. Set up the ramp as shown in the picture to the right; it will be almost vertical against the wall or table. Roll the IOLab along the ramp positioned almost vertically such that the wheels stay in contact with the ramp. Set up the software to register "Force" and "Wheel".

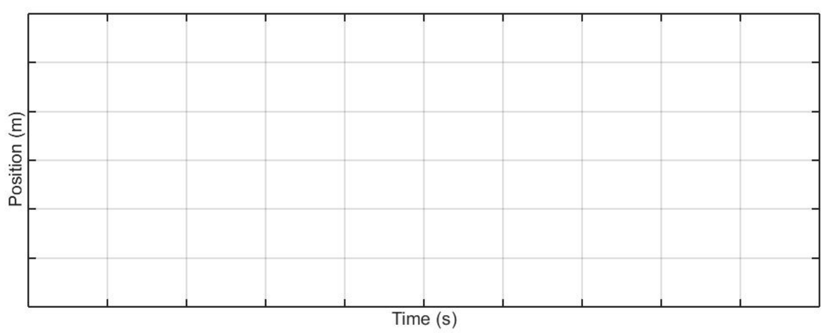
3. The force sensor should be calibrated. Click the Reverse y-axis boxes. (Remember that this just sets the +y direction as positive.)

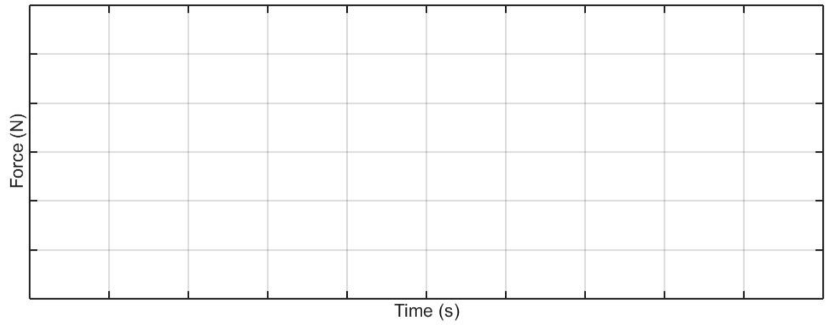
4. Begin graphing force, position, and velocity while lifting the IOLab at a slow, constant speed through a distance of about 0.5 m.

5. When you have a set of graphs in which the IOLab was moving at a reasonably constant speed, save or print them, and sketch them on the axes below.









Question 2-1: Did the force needed to move the mass depend on how high it was off the floor, or was it reasonably constant?

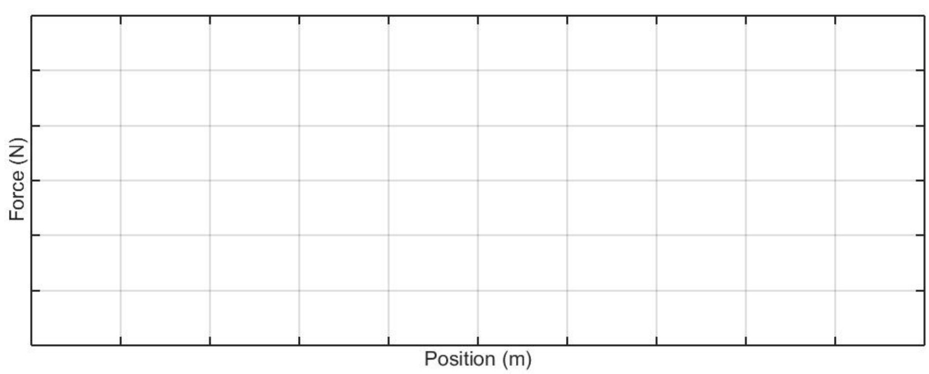
6. Use the analysis features of the software to find the average (mean) force over the distance the mass was lifted. Record this force and distance below.

Average force:______N Distance lifted:______m

7. Calculate the work done in lifting the mass. Show your calculation.

Work done:______J

8. Plot Force vs Wheel (Ry). This called the "Parametric plot mode", indicated by the button . Check the boxes for the wheel and the force sensor in that order. (**Note: Selecting the force sensor first and the wheel second will result in an erroneous parametric plot. If that happens, deselect Force and Reselect it.)** Record your data, and then select the parametric plot button (). Click-and-drag the data below the "Force vs. Wheel plot" to plot those parts of the two quantities that are relevant. Save or print the graph, and sketch it on the axes below.



8. Notice that force times distance is also the area of the rectangle under the force vs. position graph. One can find the area under the curve by counting squares for instance. In some cases, as we saw before, it can be calculated without resorting to counting unit squares.

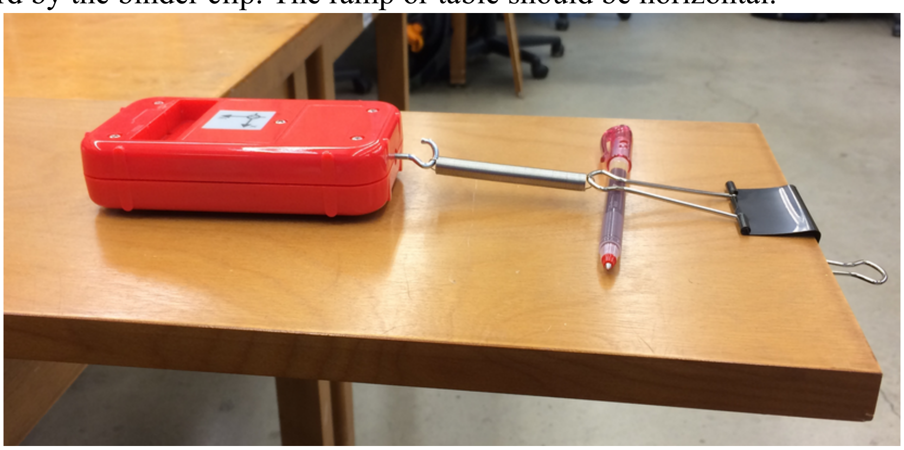
> **Comment:** This activity has dealt with the constant force required to lift an object against the gravitational force at a constant speed. The area under the force vs. position curve always gives the correct value for work, even when the force is not constant. (If you have studied calculus you may have noticed that the method of calculating the work by finding the area under the force vs. position graph is the same as integrating the force with respect to position.)

If you have time, do Extension 2-2 to find the work done by the non-constant spring force using from the area under the force vs. position graph.

Extension 2-2: Work Done by a Nonconstant Spring Force

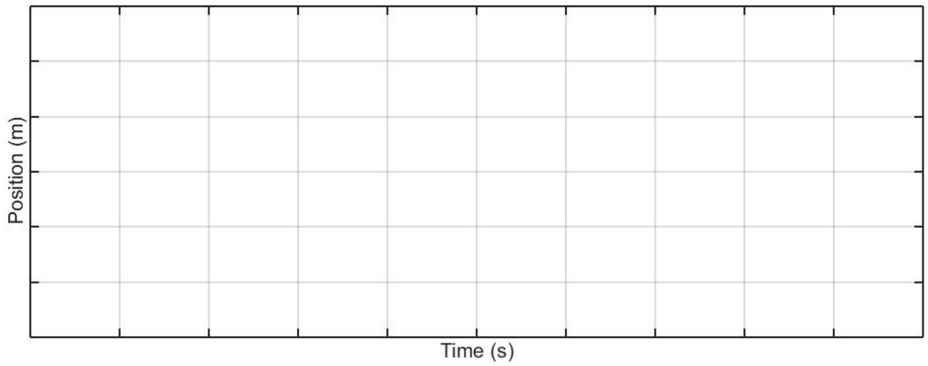
In this extension you will measure the work done when you stretch a spring through a measured distance. First you will collect data for the force applied by a stretched spring vs. distance the spring is stretched, and you will plot a graph of force vs. distance. Then, as in Activity 2-1, you will be able to calculate the work done by finding the area under this graph.

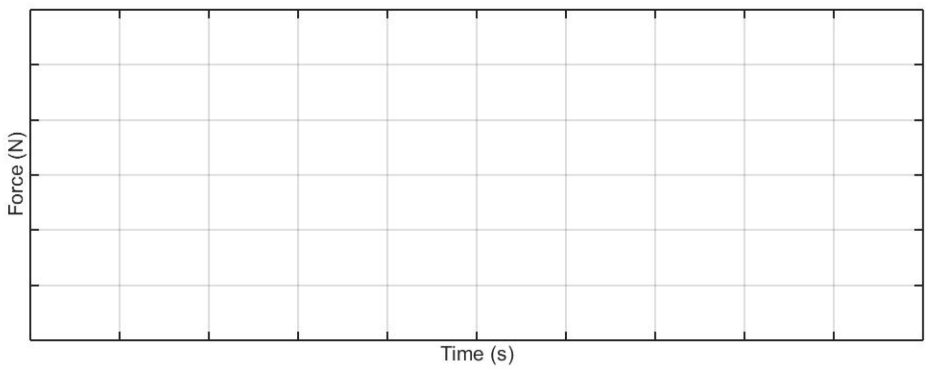
1. Set up the ramp, IOLab, and spring as shown in the diagram. The string is attached to the board by the binder clip. The ramp or table should be horizontal.



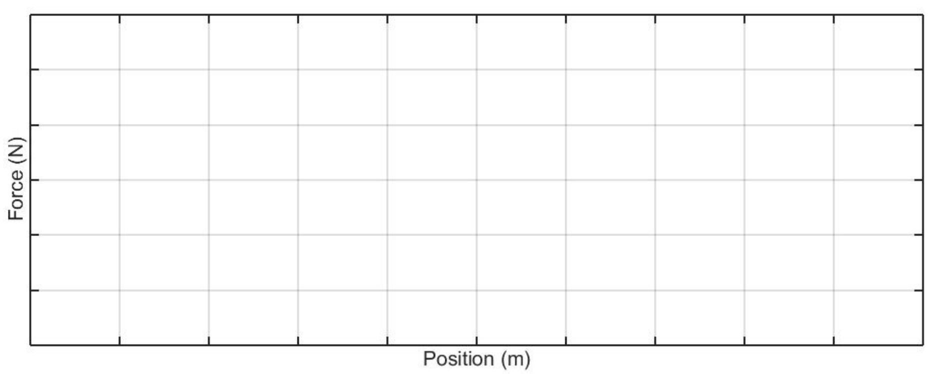
> **Comment:** We assume that the force measured by the force sensor is the same as the force applied by the cart to the end of the spring. This is a consequence of *Newton's third law.*

2. Open the IOLab software and display the force vs. time and wheel vs time. Click the Reverse y-axis boxes. (Remember that this just sets the +y direction as positive.) Begin graphing force and position as the IOLab is moved such that the spring gradually stretches from its equilibrium length (with no force pulling on its en**d), y=0.**0 to y=0.2 m. Save or print your graphs for force and position as functions of time, and sketch them on the axes below.





3. Then, as before, do a parametric plot of force vs. position. Save or print and sketch your graph. When the spring is unstretched, the force should read zero.



4. Calculate the spring constant from the graph above as the slope of the force as a function of the position by drawing a straight line through your data points. You can also use the Excel (see Appendix).

k=__________ N/m

Question E2-3: Compare this force vs. position graph to the one you got lifting the mass in Activity 2-1. Is the spring force a constant force? Describe any changes in the force as the spring is stretched.

Question E2-4: Can you use the equation $W = F_x \Delta x$ for calculating the work done by a non-constant force like that produced by a spring? Explain.

4. Calculate the work done in stretching the spring using the area.

Area under force vs. position graph:______J

Investigation 3 will begin with an exploration of the definition of *kinetic energy.* Later, we will return to this method of measuring the area under the force vs. position graph to find the work, and we will compare the work done to changes in the kinetic energy.

INVESTIGATION 3: KINETIC ENERGY AND THE WORK–ENERGY PRINCIPLE

What happens when you apply an external force to an object that is free to move and has no frictional forces on it? According to *Newton's second law,* it should experience an acceleration and end up moving with a different velocity. Can we relate the change in velocity of the object to the amount of work that is done on it?

Consider a fairly simple situation. Suppose an object is lifted through a distance and then allowed to fall near the surface of the Earth. During the time it is falling it will experience a constant force as a result of the attraction between the Earth and the object—the gravitational force. You discovered how to find the work done by this force in Investigations 1 and 2. It is useful to define a new quantity called *kinetic energy.* You will see that as the object falls, its kinetic energy increases as a result of the work done by the gravitational force, and that, in fact, it increases by an amount exactly equal to the work done.

First you need to find a reasonable definition for the *kinetic energy.* You will need the following:

- two thick books

Activity 3-1: Kinetic Energy

In this activity you will explore the meaning of kinetic energy, and see how it is calculated.

1. Toss one book up in the air and catch it. If you throw it faster it will go higher. Alternate between fast tosses and slow tosses. Notice how much effort it takes to throw it and to catch (stop) it when it is moving quickly or slowly.

Question 3-1: Does the effort needed to stop the book seem to change as its speed increases? How does it change? Explain.

Question 3-2: Does the effort needed to throw the book seem to change as its speed increases? How does it change? Explain.

2. Now toss the two books together (some rubber bands will help in having them stay together). Compare tosses of one and two books that go up at the same speed. Again notice how much effort it takes to toss and stop the book(s).

Question 3-3: Does the effort needed to stop the two books seem to change as its mass increases compared to a single book? How does it change? Explain.

Question 3-4: Does the effort needed to throw the two books seem to change as the mass increases compared to a single book? How does it change? Explain.

Comment: When an object moves, it possesses a form of energy because of the work that was done to start it moving. This energy is called *kinetic energy.* You should have discovered that the amount of kinetic energy increases with both mass and speed. In fact, the kinetic energy is defined as being proportional to the mass and the square of the speed. The mathematical formula is

$$K = \frac{1}{2}\, m\, v^2$$

The unit of kinetic energy is the joule (J), the same as the unit of work.

Activity 3-2: Your Kinetic Energy

In this activity you will examine how you can graph the kinetic energy of an object such as your body in real time. You will need the following:

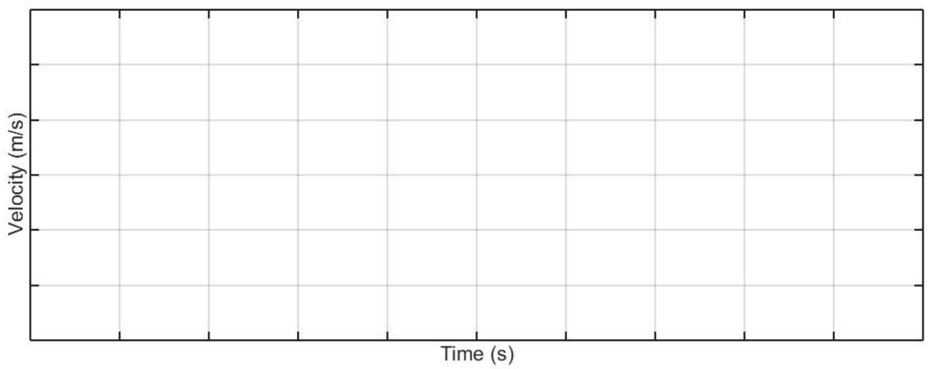
• IOLab
• a string about 2 m long

1. Open up the software and select the Wheel.

2. To display kinetic energy you will need to know your mass in kilograms. Use the fact that 1.0 kg weighs 2.2 lb on Earth to find your mass in kilograms.

Mass:______kg

3. Attach the string to one end of the IOLab. You are ready to record your velocity as you walk your IOLab – like a dog. Begin graphing while walking away from the computer slowly, then more quickly, and then stop. Now, carefully so the IOLab does not turn around, walk slowly back toward the computer. Save or print your graph for velocity vs. time and sketch it below.



Question 3-5: Now calculate your kinetic energy at several instances while moving away from your computer and when you are moving back to the computer using your mass and the velocity recorded by the IOLab. Is it possible to have negative kinetic energy? Explain.

Question 3-6: Which would have a greater effect on the kinetic energy—doubling your velocity or doubling your mass? Explain.

When you apply a force to an object in the absence of friction, the object always accelerates. The force does work and the kinetic energy of the object increases. Clearly, there is some relationship between the work done on the object and the change in its kinetic energy.

Prediction 3-1: What do you think is the relationship between work done and change in kinetic energy of an object? Explain.

In the next activity, you will examine this relationship, called the *work–energy principle,* by doing work on the IOLab with a spring.

Activity 3-3: Work–Energy Principle

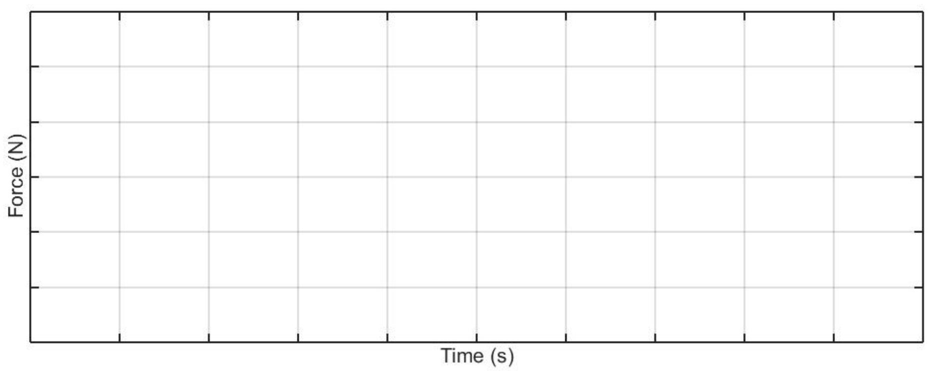
1. Measure the mass of the IOLab by hanging it from the spring. Make sure you calibrate the force sensor with no force applied.

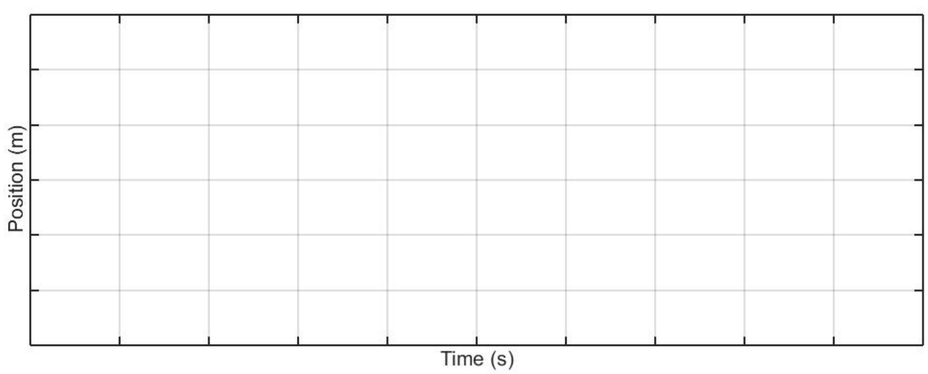
Mass of IOLab:__________kg

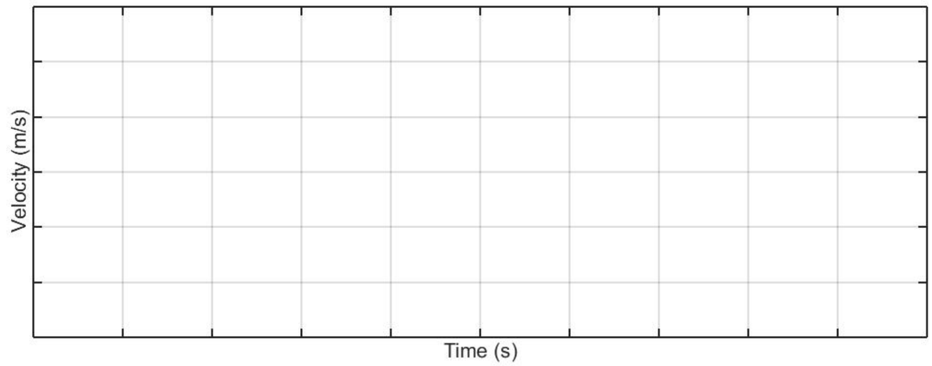
2. Set up the IOLab, string, and spring as shown in the diagram in Extension 2-2.

3. Select force and wheel. Zero the force sensor with no tension on the spring. Click the Reverse y-axis boxes. (Remember that this just sets the +y direction as positive.)

4. Begin graphing, and then pull the IOLab along the board so that the spring is stretched about 20 cm from the unstretched position. Release the IOLab, allowing the spring to pull it back at least to the unstretched position. When you get a good set of graphs, save or print them, and sketch them on the axes below. Carefully label, on the graph, the various stages of the motion of the IOLab.



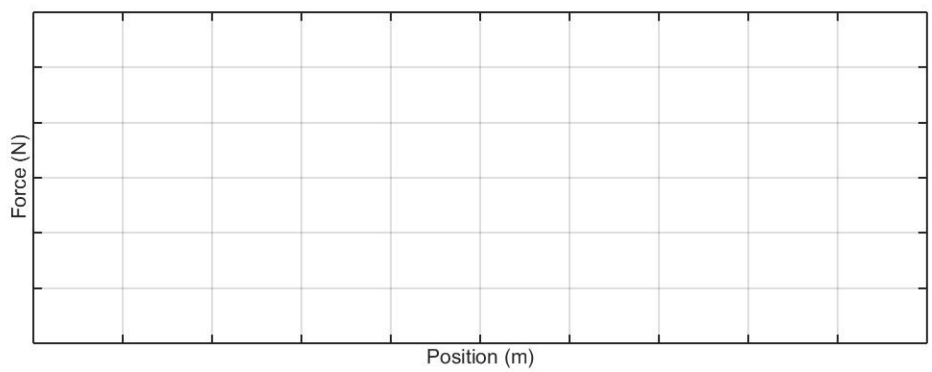




5. Change to a the force vs position graph using the "Parametric plot mode". Save or print your graph, and sketch it on the axes below.

6. Calculate the value of the work done by the spring by calculating the area under the curve of the force vs position graph. The position should go from 20 cm to zero. The force will go from its maximum to zero as well, so make sure you zoom in on the right part of the graph. The data gets more difficult to interpret when the spring is fully retracted. Show your calculation.

Work done by spring________ J



7. Calculate the change in kinetic energy of the IOLab using its mass and the velocity when the force becomes zero.

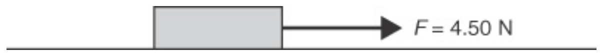
Change in kinetic energy________ J

Question 3-7: How does the work done on the cart by the spring compare to its change in kinetic energy? Does this agree with your prediction? Is there a loss due to friction? How much?

Question 3-8: State the work–energy principle that relates work to kinetic energy change in words for the IOLab and spring system that you have just examined.

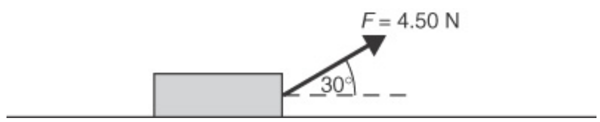
HOMEWORK FOR Lab 9:
WORK AND ENERGY

1. The block below is pulled a distance of 2.50 m. How much work is done by the force? Show your work and include units.



Answer:______

2. Now the force acts in a direction 30° above the horizontal as shown below. If the block is again moved 2.50 m, how much work is done by the force? Show your work and include units.



Answer:______

3. Two objects of different mass start from rest, are pulled by the same magnitude net force, and are moved through the same distance. The work done on object A is 500 J. After the force has pulled each object, object A moves twice as fast as object B. Answer the following questions and show your work.

How much work is done on object B? ______

What is the kinetic energy of object A after being pulled? ______

What is the kinetic energy of object B after being pulled? ______

What is the ratio of the mass of object A to the mass of object B? ______

4. An object of mass 0.550 kg is lifted from the floor to a height of 3.50 m at a constant speed.

How much work is done by the lifting force (include units)?

How much work is done by the gravitational force on the object?

What is the *net* work done on the object?

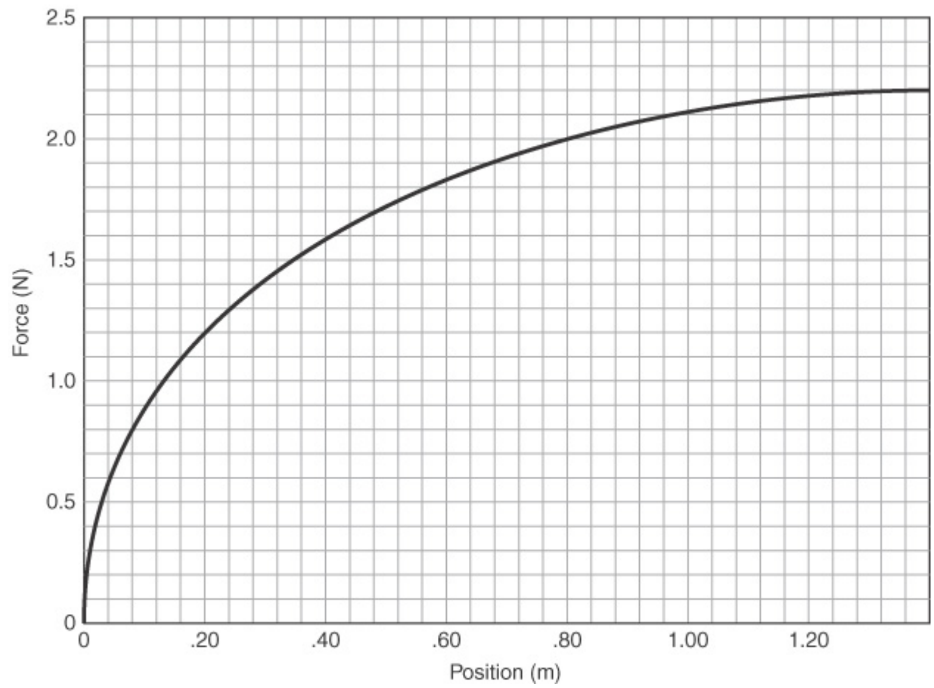
What is the change in kinetic energy of the object?

Are your results consistent with the work-energy principle? Explain.

5. If the object in Question 4 is released from rest after it is lifted, what is its kinetic energy just before it hits the floor? What is its velocity? Show your work and include units.

Answers: Kinetic energy:______ Velocity:______

6. A force acts on an object of mass 0.425 kg. The force varies with position as shown in the graph that follows.



Find the work done by the force in moving the object from 0.40 m to 1.20 m. Explain your calculation and give units.

Answer:______

7. Assuming that there is no friction and that the object in Question 6 starts from rest at 0.40 m, what is the object's kinetic energy when it reaches 1.20 m? Show your calculation and give units.

Answer:______

8. What is the velocity of the object in Question 6 when it reaches 1.20 m? Show your calculation and give units.

Answer:______