# Lab 8: Work and Energy

Objectives:

- To understand the concept of work
- To be able to calculate work for constant and non-constant forces
- To understand the concept of kinetic energy
- To understand the relationship between work and kinetic energy

Equipment:

- Computer-based laboratory system
- motion detector
- Real-Time physics mechanics experiment configuration files
- force probe
- two 1kg masses
- low friction cart
- ramp
- meter stick
- protractor
- string
- spring
- 500g mass

Exploration 1 Prediction

You are asked to choose one of three jobs involving lifting boxes. You can a) lift 100 50 lb. boxes through a distance of 20 ft., b) lift 50 100 lb. boxes through a distance of 10 ft., or c) lift 100 50 lb. boxes a distance of 30 ft. along a 30° incline on frictionless rollers. The three situations are pictured below. Which one would you choose, based on the effort you would have to expend? Explain your reasoning.
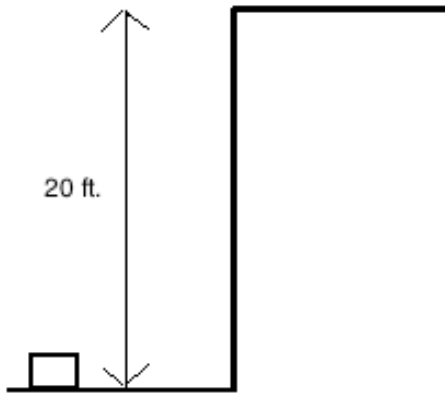
(a)
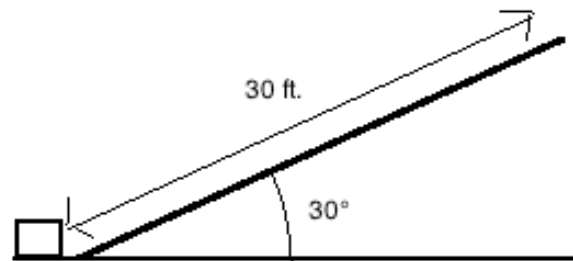
(c)
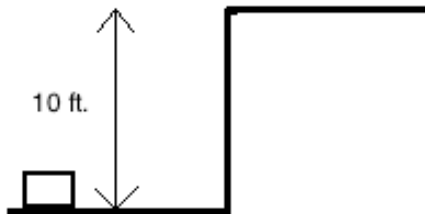
(b)

Exploration 2 Effort and Work

Exploration 2.1 Do the following tasks and answer the following question.

   I.   Lift 1 kg mass at slow constant speed from the floor to a height about 1m.
   II.   Push 1 kg mass 1m along the floor at a constant speed.

In both cases, why you need to exert a force to move the object?

Exploration 2.2 Do the following tasks and answer the following question.

   I.   Lift 1 kg mass at slow constant speed from the floor to a height about 1m.
   II.   Lift two 1 kg masses at slow constant speed from the floor to a height about 1m.

Which task takes more effort?

Exploration 2.3 Do the following tasks and answer the following question.

   I.   Lift 1 kg mass at slow constant speed from the floor to a height about 1m.
   II.   Lift 1 kg mass at slow constant speed from the floor to a height about 2m.

Which task takes more effort?

Exploration 2.4 If work were defined as effort, how are work and force, and work and displacement related?

In physics, work done by a constant force is defined as follows:

> The work done on an object by an agent exerting a constant force on the object is the product of the component of the force in the direction of the displacement and the magnitude of the displacement.

Mathematically, for a constant force,

$$W = F_{\parallel}d = Fd\cos\theta$$

where F is the forces, $F_{\parallel}$ is the component of the force in the direction of displacement, d is the displacement and θ is the angle between the force and the displacement. This can also be written as the dot product of force and displacement $W = \mathbf{F \cdot d}$.

If the force is not constant,

$$W = \int \mathbf{F \cdot ds}$$

where **F** is the force and **ds** is a small displacement. If you have had calculus, you will notice that the work is area under the curve when the magnitude of the force in the direction of motion, $F_{\parallel}$, is plotted vs. the position.

The work can be positive, negative or zero. It is useful to examine the sign of the work: a) if the component of the force is in the direction of the displacement, the work is positive, b) if the component of the force is opposite to the direction of displacement, the work is negative, c) if the force is perpendicular to the displacement (θ = 90°), the work is zero.

Is this consistent with your observations in Explorations 1.1 – 1.4?

Exploration 3 Calculating the work done

Exploration 3.1.a

A block is pulled at constant speed a distance of 2.50m with a 4.5N horizontal force. Calculate the work done by the pulling force. Show your work below.

$F = 4.5N$
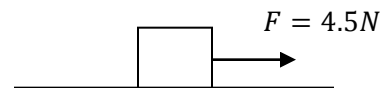
Exploration 3.1.b

Calculate the work done by the frictional force for the case in Exploration 3.1.a. Show your work and explain below.
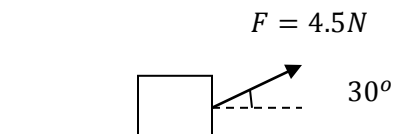
Exploration 3.1.c

Calculate the net work (sum of work done by all forces) for the case in Exploration 3.1.a. Show your work and explain below.

Exploration 3.1.d

Calculate the work done by the normal force and the gravitational force for the case in Exploration 3.1.a. Show your work and explain below.

Exploration 3.2.a

A block is pulled at constant speed a distance of 2.50m with a 4.5N force tilted 30° from the horizontal. Calculate the work done by the pulling force. Show your work below.

$F = 4.5N$

30°

Exploration 3.2.b

How does the magnitude of the work done by the frictional force in this case compare to the magnitude of the work done by the frictional force in Exploration 3.1.b? Show your work and explain.

Investigation 1 Calculating Work When Force and Displacement are in Same and Different Alignment
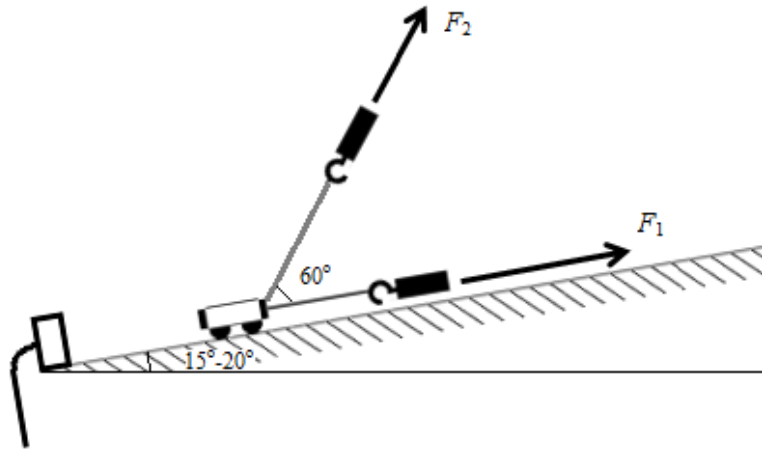
Investigation 1.1

a) Open the experimental file called "**Force and Work (L11A1-2)**" to display the axes below.
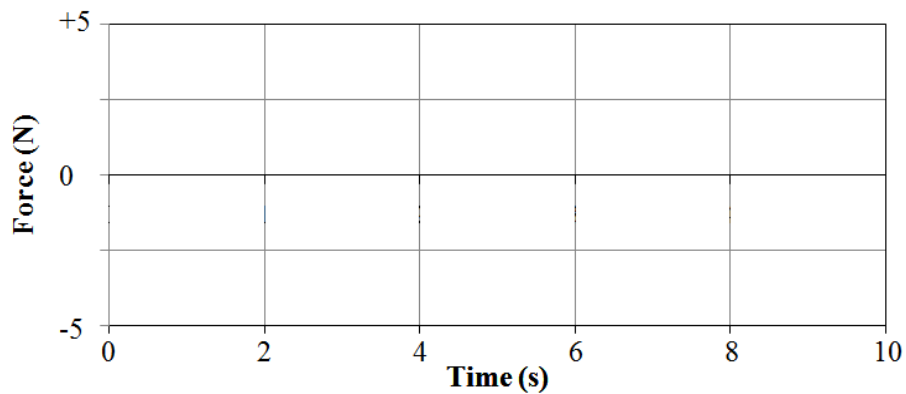
b) Calibrate the force probe with a 500g mass.

c) Setup the ramp, cart, force probe as seen below in the figure.

d) Zero the force probe.

e) Find the force needed to pull the cart up the ramp at a constant velocity for the following cases:

i. Pull the cart parallel to the ramp (F_1).

ii. Pull the cart at an angle of $60°$ to the surface of the ramp (F_2).

Record the data for each case and store it. Then graph both cases on the same force-time graph above.

Investigation 1.2 Use the statistics in the analysis feature to find the mean force for each of the previous cases.

$F_1 =$ N

$F_2 =$ N

Is your data consistent with your predictions based on your calculations in Exploration 3?

Investigation 2 Work Done by a Constant Lifting Force

In this investigation, you will examine how work can be calculated by calculating the area under the curve of the magnitude of the force in the direction of motion plotted vs. the position. You will use a constant force to lift an object a measured distance.

Investigation 2.1

a) Place the motion detector on the floor, pointing upward.

b) Calibrate the force probe with a 500g mass.

c) Open the experimental file called **"Work in Lifting (L11A2-1)"** to display the axes below.
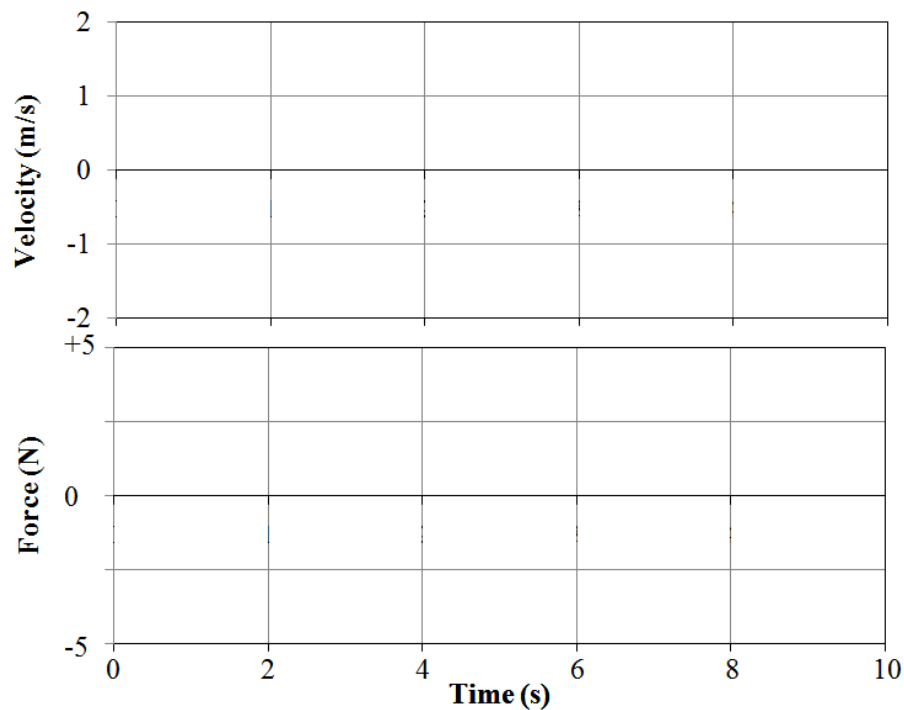
d) Zero the force probe and the motion detector, and hang a 200g mass from the end of the force probe. Begin graphing while lifting the mass at a slow constant speed through a distance of 1.0m starting at least 0.5m above the motion detector.

e) When you have a set of graphs in which the mass was moving with a reasonably constant speed, sketch your graphs on the axes above.

Record the value of the constant force:

        Force _____

Investigation 2.2 Change the force-time graph axes to force-position. Sketch your data on the following graph. (Put the mouse pointer on the time axes and click on right click and change it to position)
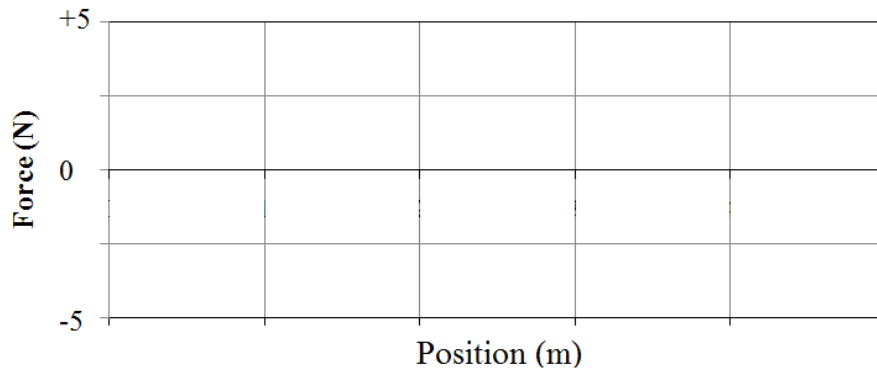
Use the analysis and statistics features of the software to find the average force over the distance the mass was lifted.

    Average force _____   Distance lifted_____

From this data, calculate the work done in the lifting the mass. Show your calculations.

                Work done _____

Investigation 2.3 The work can also be calculated by finding the area under the curve when the force is plotted vs. position. Using the force-position graph find the area under the curve directly using the integration routine in the software.

          Area under the force-position graph _____

Compare the value of work you calculated in Investigation 2.2 with the area found in this part.

How do they compare?

How do you expect them to compare? Explain.

Investigation 3 Work Done by a Non-constant Force

A spring does not exert a constant force on an object. The force of a spring is given by the equation

$$F = -k\Delta x$$

where k is a constant and Δx is the displacement of the spring from the equilibrium position. In this investigation, you will examine the work done on an object by a non-constant force.

Investigation 3.1

a) Set up the ramp, cart, flag, motion detector, force probe, and spring as shown in the following figure. The total distance between the motion detector and cart should 1.5m.

b) Calibrate the force probe with a 500g mass.

c) Open the experimental file called "**Stretching Spring (L11E2-2)**" to display the axes below.

d) Zero the force probe with the spring hanging loosely. The zero point of the motion detector should be at the initial position of the cart. Then begin graphing force vs. position as the cart is moved slowly towards the motion detector until the spring stretched to 1m. Sketch the force vs. position graph below.
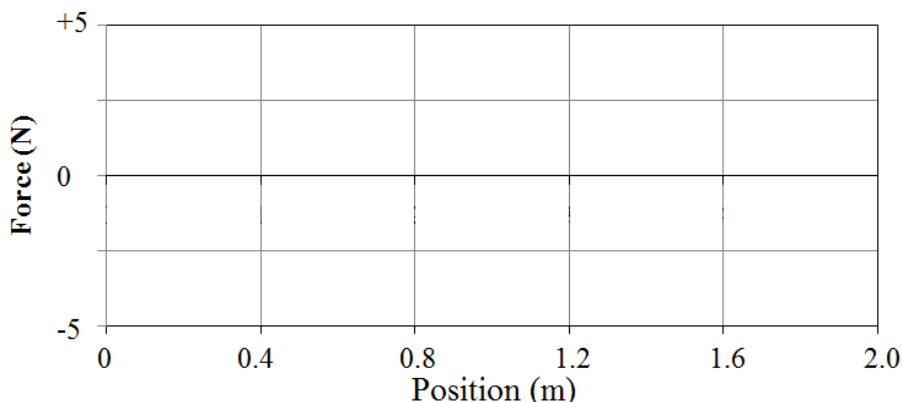
e) Can you use the equation $W = F_x \Delta x$ for calculating the work done by a non-constant force like the one produced by the spring? Explain.

Investigation 3.2 Find the work done in stretching the spring 1m by using the integration routine to find the area under the force vs. position graph.

Area under the force vs. position graph_____

If you are studying calculus-based physics, calculate the work done by the spring in terms of the spring constant k. Show your work below.

Use this equation to determine the spring constant. Show your work.

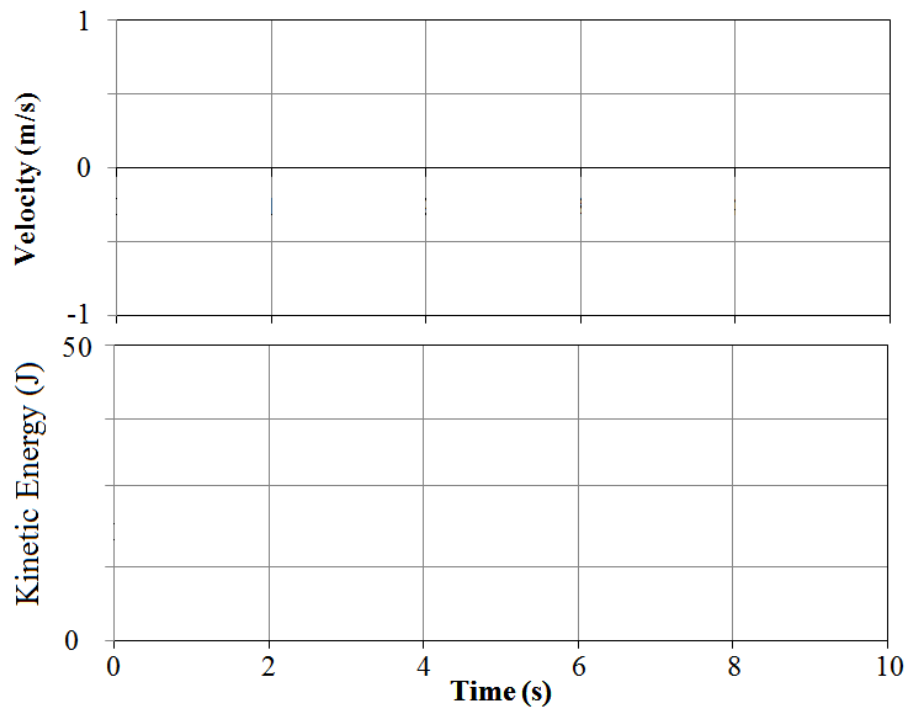Spring constant _____

Investigation 4 Kinetic Energy

The kinetic energy is defined mathematically as

$$K = \frac{1}{2} mv^2$$

It depends both on the mass, m, and the velocity, v.

Investigation 4.1

a) Open the experimental file called " **Kinetic Energy (L11A3-2)**" to display the axes below.

b) To calculate your kinetic energy you will need to know your mass in kilograms. Use the fact that 1.0kg weighs 2.2 lbs. to calculate your mass:

Mass _____

Enter your mass in the kinetic energy equation in the software. You can do that by clicking on the kinetic energy with the right click, then enter your mass instead of 1.

c) Configure the software with a new column calculated from ½ of your mass times the square of your velocity measured by the motion detector. Then both velocity and kinetic energy will be graphed in real time.

d) Begin graphing by walking slowly away from the motion detector, then more quickly, and then back toward the motion detector slowly and then faster. Sketch your graphs on the graph above.

e) How does the kinetic energy graph differ from the velocity graph? Is it possible to have a negative kinetic energy? Explain.

Investigation 4.2 Which one would have a greater effect on the kinetic energy, doubling the mass or doubling the velocity? Explain.

Investigation 4.3 What is the relationship between work done on an object and the change in kinetic energy of an object?

Investigation 5 Work and Kinetic Energy

Investigation 5.1 Predict the relationship between the work done on an object and the change in kinetic energy of the object.

Investigation 5.2

a) Set up the ramp, cart, flag, motion detector, force probe, and spring as shown in the following figure. The total distance between the motion detector and cart should 1.5m.

b) Calibrate the force probe with a 500g mass.

dc Open the experimental file called **"Work-Energy (L11A3-3)"** to display the axes below.

d) Measure the mass of the cart and enter this value in the kinetic energy formula in the software.

Cart Mass _____

e) Zero the force probe with the spring hanging loosely.

f) Pull the cart along the ramp so that the spring is stretched about 1.0 m from the unstretched position.

g) Begin graphing and release the cart, allowing the spring to pull it back at least to the unstretched position. Sketch the graphs below.
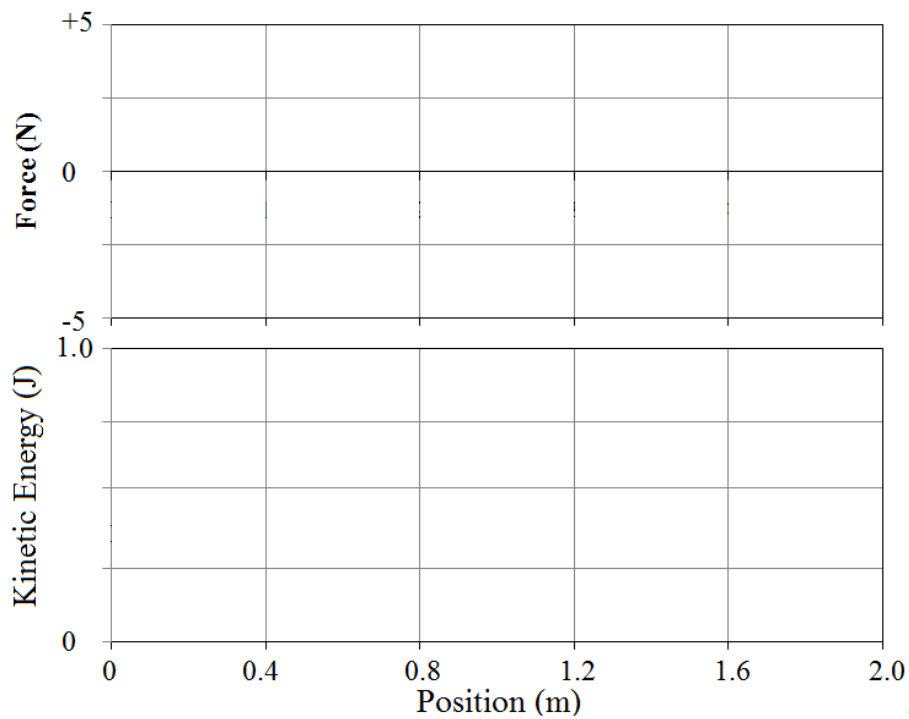
h) Use the integration routine to find the area under the curve (work done) by the spring force for a displacement between two positions.

Work _____

i) Use the kinetic energy graph to find the change in kinetic energy between the two points you chose in part (h).

Change in kinetic energy _____

Investigation 5.3 How does the work done compare to the change in kinetic energy?

Does the data support your prediction in Investigation 5.1?

State in words and equations the work-energy principle that relates work to change in kinetic energy for the cart and spring system you have just examined.