

Module VII: Work

OBJECTIVES/PURPOSE

Students will:

- define the concept of work as force times distance
- distinguish the relation of work to energy
- apply the concept of work to an object
- compare alternate forms of energy and conversion of one form to another
- identify, understand and utilize key concepts and formulas

MATERIALS

| | |
|------------------------|------------------------------------------------------------------|
| Calculator | K'NEX car |
| Spring scale | K'NEX Inclined/Looper Physics Lab Station and Roller Coaster |
| Tape measure (~1m) | Vertical heights of inclined plane and Roller Coaster (Module I) |
| Mass of car (Module V) | Average force along inclined plane (Module V) |

KEY CONCEPTS

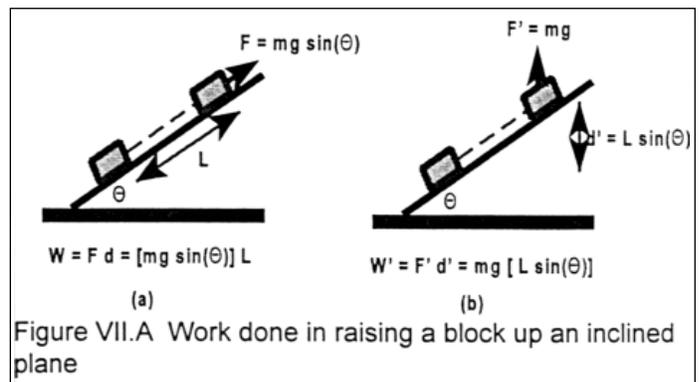
| | |
|--------|-----|
| Force | [F] |
| Work | [W] |
| Energy | [E] |
| Joule | |

FORMULAS

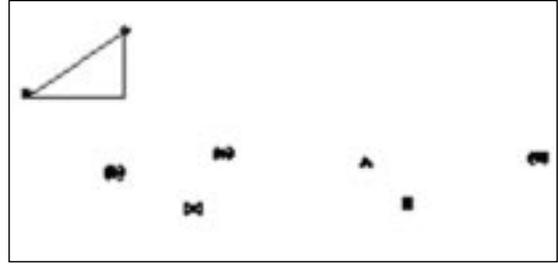
| | |
|-------|------------------------------------------------------|
| Work | $W = \text{force} \cdot \text{distance} = F \cdot d$ |
| Joule | $J = N \cdot m = kg \cdot m^2 / sec^2$ |

CONCEPTS REVIEW

In science, **work** is defined as a force acting through a distance. When a force is applied in the same direction as the displacement it causes, the formula for work is $W = F \cdot d$. This formula implies that two conditions must be met in order for work to be done. First, a force must be applied. Second, the object must *move*, as a result of the applied force, in the *same direction* as the force. In this sense, if a person pushes hard on a heavy box, but the box does not move, then no work has been done, although the person is applying a force. Similarly, if a person is holding a 50kg box and walks across a level floor for 20m, no work has been done, although the person may feel tired.



The force needed to hold the box up against the force of gravity is in an upward direction, while the walking motion is in a horizontal direction, so the force and the displacement are not in the same direction. [Actually, work is done as the person's muscles extend and contract while walking and overcoming frictional forces. These are ignored here.]



Work is done when the person lifts the box up. In this case, the force applied by the person to oppose gravity and the direction of movement are in the same direction. If the force is not in the same direction as the displacement, the work is calculated as $W = F \cdot d \cos(\theta)$, where θ is the angle between the direction of the force and the displacement (see Figure VII.A).

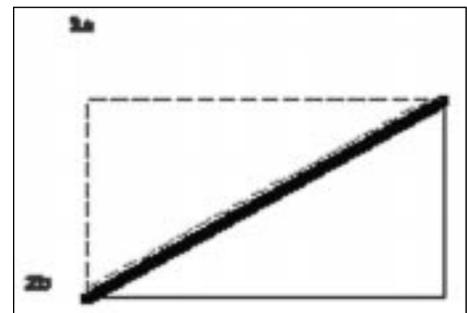
This equation reduces to the results discussed in two special cases. When the force is in the direction of the displacement $\theta=0^\circ$, $\cos(\theta)=1$, $W=F \cdot d$. When the force is perpendicular to the displacement, then $\theta=90^\circ$, $\cos(\theta)=0$ and $W=0$. If the motion is in the opposite direction to the applied force, then $\theta=180^\circ$, $\cos(\theta)=-1$ and $W=-F \cdot d$.

There are two ways to think of this general formula for work. These are illustrated in Figure VII.A which shows the work done in raising a block up an inclined plane. In Figure VII.A(a), the total distance the block is moved along the track, L , is multiplied by the force along the track in the direction of the displacement, $F=mg \cdot \sin(\theta)$. In Figure VII.A(b) the total vertical distance moved, $d=L \cdot \sin(\theta)$, is multiplied by the force of gravity in the vertical direction, $F=mg$. Note that both methods yield the same value for the work $W=W=mg \cdot L \cdot \sin(\theta)$.

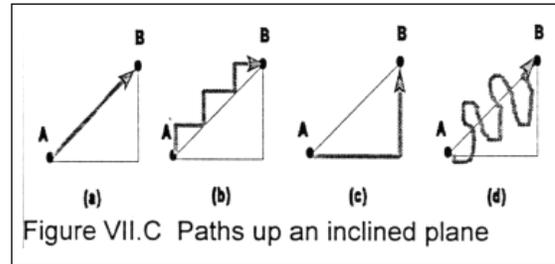
Another way to describe work is as the amount of **energy** added to an object by doing something to the object (e.g. moving it). Stated another way, when work is done on an object, something is added to the object; this "something" is referred to as energy. Understanding the concepts of energy is paramount in understanding physics.

Based on the prior information about work, it is clear that the same amount of work is required to move an object up an inclined plane via Path 1 of Figure VII.B as is required to lift an object straight up (Path 2a) and then horizontally (Path 2b), which requires no work. In fact, as long as there are no dissipative forces (e.g. friction or heat) involved which cause energy to be removed from the system, the amount of energy required to get from one point to another is entirely independent of the path taken. Thus, all the paths illustrated in Figure VII.C require the same amount of work. This is explained further in the study of conservation of energy and energy dissipation.

A dimensional analysis confirms that work has units of energy. Considering the formula for work, $W=F \cdot d$, then, from Newton's Second Law of Motion, $W=(\text{mass} \cdot \text{acceleration}) \cdot \text{distance}$. This has dimensions $(\text{mass} \cdot [\text{length}/\text{time}^2]) \cdot \text{length}$ or $\text{mass} \cdot \text{length}^2/\text{time}^2$. These are the same dimensions as other forms of energy, such as kinetic energy or potential energy.



There are numerous alternate forms of energy to consider when discussing work along with the conversion of one form to another. The MKS unit of work and energy is the **joule**. One joule is defined as the force needed to move one newton a distance of one meter or $1 \text{ joule} = 1 \text{ kg} \cdot \text{m}^2/\text{sec}^2$. In the cgs system, the unit of work is the erg, which is equal to one dyne acting over one centimeter or $1 \text{ g} \cdot \text{cm}^2/\text{sec}^2$; $1 \text{ joule} = 10,000,000 \text{ ergs}$.



Lifting a mosquito onto a plate requires about one erg. The unit of work in the English system is the foot-pound (ft-lb); with the pound as a unit of force, not mass. One ft-lb is equal to 1.356 joules. In quantum mechanics, a unit used to measure the work of atoms is the electron volt or eV which is the energy required to move a single electron through one volt or about one millionth of an erg. $1 \text{ joule} = 1.6 \cdot 10^{-19} \text{ eV}$. In thermal measurements and chemistry, a common unit of energy is the calorie; 1 cal is equal to 4.186 joule.

PROCEDURE FOR STUDENT ACTIVITY

Students will make force measurements as the car is pulled along different tracks, using a spring scale. It is important that the scale measures the correct range of force to provide accurate measurements. The maximum force that needs to be measured is the weight of the car, approximately 1.0 Newtons or 0.25 lbs. Note that scales are often calibrated in units of mass; the equivalent mass is 0.11 kg.

Scales that measure much larger forces than this will not typically have the required resolution to measure the small forces encountered on the low-angle inclined planes. If scales designed to measure larger forces are the only ones available, you may wish to add up to 200 g of mass to the car so that the scale readings are in a measurable range.

Module VII: Work

PURPOSE

To understand the concept of work in relation to force, distance and energy; apply concept of work to an object

PROCEDURE

Make force measurements with spring scales for an object traveling along an incline.

MATERIALS

| | |
|-----------------------------------------------|------------------------------------------------------------------|
| Calculator | K'NEX car |
| Spring scale | K'NEX Inclined/Looper Physics Lab Station |
| Mass scale | Mass of car (Module V) |
| Tape measure (~1 m) | Vertical heights of inclined plane and Roller Coaster (Module I) |
| Average force along inclined plane (Module V) | |

KEY CONCEPTS

| | |
|--------|--------------|
| Force | [<i>F</i>] |
| Work | [<i>W</i>] |
| Energy | [<i>E</i>] |
| Joule | |

FORMULAS

| | |
|-------|------------------------------------------------------|
| Work | $W = \text{force} \cdot \text{distance} = F \cdot d$ |
| Joule | $J = N \cdot m = kg \cdot m^2 / sec^2$ |

INQUIRIES

1) Place the car at the bottom of the low-angle inclined plane. Slowly pull the car to the top of the incline. By doing this, work is being done to the car. What is added to the car when this work is done?

2) What would happen if you let go of the car as it sits at the top of the hill? What would happen to the energy that was added?

3) Place the car at the bottom of the low angle inclined plane and mark the location of the back wheels on the track. Now pull the car up the track until it has been raised 10 cm vertically; mark the location of the back wheels again. Measure this distance along the track and record it in Table VII.1. Also record the angle of ascent.

4) Now attach a spring scale to the front of the car. Slowly pull the car up the track from the lower mark to the higher mark. Be careful to maintain a constant speed. Read the scale. Does the measurement change while you are pulling? Why or why not? Record the average value in Table VII.1 first in the units on the scale and then in the MKS unit of force, the newton.

5) Repeat these steps for the medium and high angle inclined planes. Enter the results in Table VII.1. Also complete the entries in the table for lifting the car vertically 10cm and for moving the car horizontally along the floor.

Table VII.1

| Section of Track Traversed | Angle of Ascent - (°) | Calculated Force $F_{\text{calc}} = m \cdot g \sin(_) \text{ (N)}$ | Measured Force Along Track | |
|-------------------------------------|--------------------------|------------------------------------------------------------------------|----------------------------|-----|
| | | | (Scale Units) | (N) |
| Low angle inclined plane | | | | |
| Medium angle inclined plane | | | | |
| High angle inclined plane | | | | |
| Lifting car straight up | | | | |
| Moving car horizontally along floor | | | | |

6) Consider four different paths which can be followed to raise the car a vertical distance of 10cm: (i) along a low angle inclined plane, (ii) along a medium angle inclined plane, (iii) along a high angle inclined plane and (iv) first horizontally along the floor and then vertically. Will the amount of energy added to do this work be the same for each test? Explain.

7) On Table VII.1, rank in order from 1 to 4, the lowest to highest values of the angle of ascent, the distance traveled and the average force applied for each of these four different paths. What is the relationship between the angle of ascent and the distance traveled? How are the average forces related to the distances traveled?

8) What value(s) does work depend on to raise the car 20cm?

9) Write a formula combining the average force and the distance that will yield the work done in lifting the car (supposing that the work done is the same for the four paths).

10) Based on your observations, define work in your own words. What two conditions must be met for work to be done?

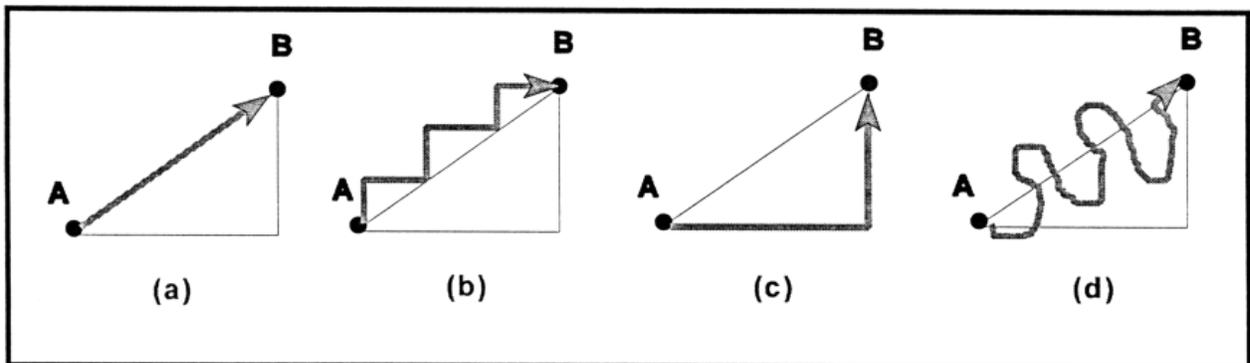
EXTENSION PROBLEMS

1) Circle true or false for each of the following questions about work. Consider only work done against the force of gravity.

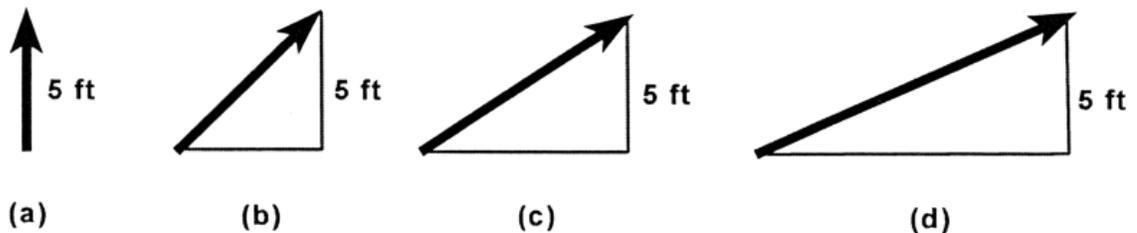
- T/F a. Doing something that causes you to sweat
- T/F b. Using your muscles to do something
- T/F c. Reading a physics book
- T/F d. Writing the answers for homework questions
- T/F e. Mowing a lawn with a push lawnmower
- T/F f. Running with a football
- T/F g. Exercising by walking for 3 miles
- T/F h. Walking up a set of stairs.
- T/F i. Kicking a soccer ball across the playing field.

2) Two weight lifters both lift the same amount of weight over their heads, but one is short and the other is tall. Do they do same amount of work? Explain your answer.

3) A box must be lifted from point A to point B. In which of the following diagrams is the most work being done? Explain your answer.



4) A box must be lifted up a vertical distance of 5 ft. In which of the following diagrams will the least force be needed to move the box? Explain your answer.



Module VII: Work

PURPOSE

To understand the concept of work in relation to force, distance and energy; apply concept of work to an object

PROCEDURE

Make measurements to determine the work done to move an object up surfaces of varying degrees of incline.

MATERIALS

| | |
|------------------------|------------------------------------------------------------------|
| Calculator | K'NEX car |
| Spring Scale | K'NEX Inclined/Looper Physics Lab Station and Roller Coaster |
| Tape measure (~1 m) | Vertical heights of inclined plane and Roller Coaster (Module I) |
| Mass of Car (Module V) | Average force along inclined plane (Module V) |

KEY CONCEPTS

| | |
|--------|-----|
| Force | [F] |
| Work | [W] |
| Energy | [E] |
| Joule | |

FORMULAS

| | |
|-------|------------------------------------------------------|
| Work | $W = \text{force} \cdot \text{distance} = F \cdot d$ |
| Joule | $J = N \cdot m = kg \cdot m^2 / sec^2$ |

INQUIRIES

- 1) Attach the spring scale to the front of the car. Slowly pull the car up the track of the low angle inclined plane. Be careful to maintain a constant speed. Record the average value of the force in Table VII.1, first in the units on the scale and then in the MKS unit of force, the newton.
- 2) List the mass of the car. Calculate the work done in raising this car 10cm vertically against the force of gravity, mg . Express this energy in units of joules.
- 3) The average acceleration along the inclined planes is given by $F_{\text{avg}} = (m \cdot g) \cdot \sin(\theta)$ (see Figure VII.1). Record the angle of ascent in Table VII.1 and calculate the force as well.

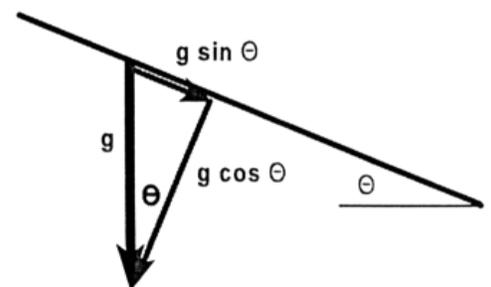


Figure VII.1

Table VII.1

| Section of Track Traversed | Angle of Ascent - (°) | Calculated Force $F_{\text{calc}} = m \cdot g \sin(_)$ (N) | Measured Force Along Track | |
|----------------------------------------|--------------------------|----------------------------------------------------------------|----------------------------|-----|
| | | | (Scale Units) | (N) |
| Low angle inclined plane | | | | |
| Medium angle inclined plane | | | | |
| High angle inclined plane | | | | |
| Ascent of first hill of Roller Coaster | | | | |

5) Place the car at the bottom of the low angle inclined plane and mark the location of the front wheels on the track. Move the car to the top of the track and mark the location of the front wheels again. Measure the distance along the track and record it in Table VII.2. Use this distance along the track and the measured average force along the track (see Table VII.1) to determine the work done in moving the car from the bottom to the top of the track. Enter the results under Method One of Table VII.2.

Table VII.2

| Section of Track Traversed | Method One | | Method Two | |
|----------------------------------------|--------------------------|-----------------------------------------------------------------|-----------------------------------|--------------------------------------------|
| | Length Along Track L (m) | Work Done Moving Car Along Track $W_1 = F_{\text{avg}}L$ (J) | Net Vertical Distance Moved h (m) | Work Done $W_2 = m \cdot g \cdot h$ (J) |
| Low angle inclined plane | | | | |
| Medium angle inclined plane | | | | |
| High angle inclined plane | | | | |
| Ascent of first hill of Roller Coaster | | | | |

6) Measure the vertical distance between the marks on the track to determine the vertical distance the car was raised. Determine the work as the vertical distance times the weight. Use the spring scale to determine the weight of the car. Record the results under Method Two of Table VII.2.

7) Repeat these steps for the medium- and high-angle inclined planes and for the ascent of the first hill on the roller coaster. Enter the results in Tables VII.1, VII.2 and VII.3.

8) In Table VII.3, compare the results of Method One and Method Two. Calculate both the difference in the values of the work and the percent difference (refer to Module II).

Table VII.3

| Section of Track Traversed | Work | |
|----------------------------------------|--------------------------|--------------|
| | Difference in Values (J) | % Difference |
| Low angle inclined plane | | |
| Medium angle inclined plane | | |
| High angle inclined plane | | |
| Ascent of first hill of Roller Coaster | | |

9) Do you have agreement between the values determined in Methods One and Two?

K'NEX ROLLER COASTER ACTIVITIES

1) Determine the amount of work required as the car is moved clockwise around the Roller Coaster track. Divide this path into a set of sections over which the slope of the track is approximately constant. Pull the car along each section using the spring scale parallel to the track and determine the average force over each section.

2) Create a table like the example shown in Table VII.4 to record the data for all of the sections along the track. Identify each section of track, record this average force (in newtons), and record the length along the track for each section. Calculate the work for each section and the sum of all the work for each section. Record these in the table.

Table VII.4 Work following a clockwise path

| Section of Track Traversed | Distance Traveled Along Section of Track (m) | Average Force Along Section of Track (N) | Work Done Moving Car Along Section of Track (J) |
|----------------------------|----------------------------------------------|------------------------------------------|-------------------------------------------------|
| | | | |
| | | | |
| | | | |
| Total Work Done: | | | |

3) Repeat these measurements following a counterclockwise path from the lowest point on the Roller Coaster track to the highest point. Create a table like the example shown in Table VII.5. Record the results of your measurements and calculations in the table.

Table VII.5 Work following a counterclockwise path

| Section of Track Traversed | Distance Traveled Along Section of Track (m) | Average Force Along Section of Track (N) | Work Done Moving Car Along Section of Track (J) |
|----------------------------|----------------------------------------------|------------------------------------------|-------------------------------------------------|
| | | | |
| | | | |
| | | | |
| Total Work Done: | | | |

4) Determine the work as the car follows a third path, first a vertical rise from the lowest point to the highest point and then a horizontal path. Complete the following measurements and calculations:

| |
|--------------------------------------------|
| Height of lowest point above floor: ____m |
| Height of highest point above floor: ____m |
| Difference in heights: ____m |
| Work done in vertical path: ____J |
| Work done in horizontal path: ____J |
| Total work done: ____J |

5) Compare your results for the total work done. What did you find to be true about the work being done in raising the car from the lowest to highest point? Compare your results to test whether the work done on the car is independent of the path. Explain your findings.

6) Show mathematically why the work done in raising the car for either case shown in Figure VII.2 (either vertically, or along the track) should be the same, neglecting frictional forces.

7) Calculate the amount of work done for each of the following:

- A 50 N box is pushed along a horizontal distance of 5m
- A 100 N box is lifted up 2m
- A 200 N box is lifted up 1m
- A 75 N person climbs up a 20m vertical mountain cliff rock climbing

