Minds•On Physics Activity

FF•27

Applying Work and Energy Ideas

Purpose and Expected Outcome

Two of the most important concepts in Physics are those of *work* and *energy*. In this activity, you will examine the work done by the electric, magnetic, and gravitational forces as objects move under the influence of these forces. After completing this activity you will be able to reason about the work done and changes of energy of bodies experiencing electric, magnetic, and gravitational forces.

Prior Experience / Knowledge Needed

You should know the definitions of *work*, *potential energy*, and *kinetic energy*. You should know that it is possible to define a potential energy for certain forces. You should be familiar with the Work–Energy Theorem. You should also have some experience analyzing and reasoning about situations using work and energy ideas.

WORK & POTENTIAL ENERGY

To estimate the amount of potential energy in a given situation, imagine doing work against a given force. For example, imagine picking up a rock off the ground. The amount of work you do to pick up the rock is also the increase in gravitational potential energy of the Earth–rock system.

Note that many forces cannot be associated with potential energy, such as the normal, tension, friction, and air resistance forces. This relationship can be applied only for *conservative* forces, such as the spring force, gravitation, and the electric force.

WORK DONE BY A NON-CONSTANT FORCE

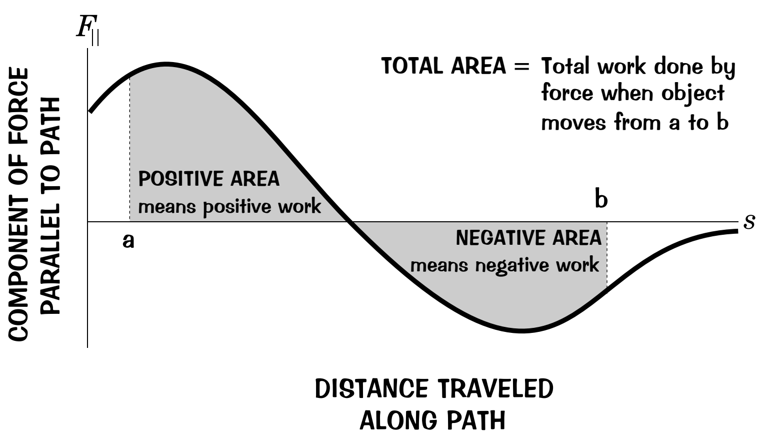
When a force is not constant, such as the force on a satellite falling back to Earth, then sophisticated mathematics are generally needed to determine the work done by that force. However, to get a rough idea of what the work might be, we can use ideas presented in *Volume 3: Conservation Laws & Concept-Based Problem Solving*.

We start with the definition of the work done by a constant force **F**:

$$W_F = F_{\parallel}\, d$$ **definition of work for a constant force**

where: $F_{\parallel} \equiv$ the component of the force **F** parallel to the displacement **d**; and
$d \equiv$ the magnitude of the displacement **d**

When the force is not constant, we simply imagine very small displacements—so small that the force may be considered constant during it. Adding up the amount of work done during each tiny displacement, we get the total work done for a given process. The total amount of work may be represented by the total area beneath the graph of $F_{\parallel}$ vs. s, where s is the total distance traveled along the actual path of the object, as shown below. (Note that s is always positive and always increasing when something is moving. Even if the object returns to its original position, the distance traveled is non-zero.)



Note that when the parallel component of the force is negative, the work done is also negative. Also, forces can be non-constant in time in addition to being non-constant in position.

Explanation of Activity

This activity consists of three parts.

PART A: Recognizing Work When Fundamental Forces are Present

Consider each of the following actions. In each case, indicate whether performing the action would cause you to do positive, negative, or zero work. Then explain your reasoning.

A1. You separate two magnets that are stuck together.

A2. You bring two negatively charged balls of STYROFOAM closer together.

A3. You lower a ten-pound weight from a table to the floor.

A4. You move the North poles of two magnets further apart.

A5. You move a thin piece of aluminum foil closer to a charged monitor.

A6. You move a neutral object toward a balloon rubbed with wool.

PART B: Recognizing Changes in Energy When Fundamental Forces are Present

Fill in a copy of the table below, showing how the (a) total energy, (b) kinetic energy, and (c) potential energy is changing for some systems. (Take each system to be large enough so that it is completely isolated, with no external agents exerting any forces on the members of the system.) Use a plus-sign (+) to indicate that the energy is increasing, a minus-sign (–) to indicate that the energy is decreasing, and zero (0) to indicate that the energy remains the same during the process described.

		(a) Total Energy (E_{total})	(b) Kinetic Energy (E_K)	(c) Potential Energy (U)
B1.	A ball is dropped from a hot air balloon and falls 100m.			
B2.	A magnet is hung from a string and slowly aligns itself with the Earth's magnetic field.			
B3.	A charged soda can is placed in contact with an insulated neutral soda can.			
B4.	The Earth orbits the Sun for 1 month.			
B5.	A bar magnet is hung from the ceiling by a string attached to its North pole and is swinging like a pendulum. A piece of magnetic material is placed under the magnet and it rapidly stops swinging.			
B6.	Two small spheres with positive charge are held together by an insulating thread. The spheres are in empty space. The string is cut and they move apart.			
B7.	A satellite is launched into orbit around the Earth.			

Reflection (for part B only)

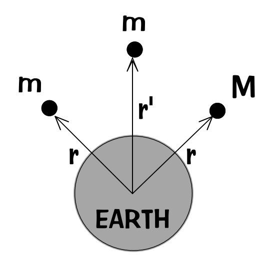
R1. What is the definition of total energy (E_{total})? Is this what you used in column (a) above?

R2. For which of the situations in part B does the total macroscopic energy (E_{macro}) change? For those cases where it changed, explain why and how it changed.

PART C: Reasoning About Work and Energy with Fundamental Forces

Answer the following questions about work and energy. Be prepared to explain your answers to your classmates.

C1. Three point masses are positioned above the Earth as shown in the diagram at right. Two of the masses are the same (m), but one of these is farther from the center of the Earth than the other ($r' > r$). The third mass is twice as large as the others ($M = 2m$) and is at the same distance as the closer of the other two masses. Consider only the interaction of each mass with the Earth.



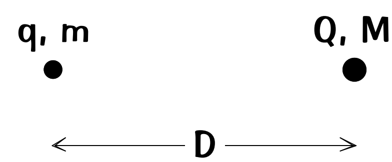
(a) Make a sketch of the gravitational force on m due to the Earth vs. its position.

(b) How would a sketch of the gravitational force on M due to the Earth vs. its position be different?

(c) After each of the three masses has fallen a distance d, which mass has had the most work done on it by the gravitational force?

(d) After each mass has fallen a distance d, which mass has the largest speed?

C2. Two small spheres are positioned a distance D apart as shown in the figure at right. The two charges, q and Q, are of the same type and are large enough to cause the spheres to repel each other despite their gravitational attraction.



Starting from a separation of D, charge Q is moved to the right while charge q is held fixed until the separation is $2D$.

(a) Does the electric force do positive work or negative work?

(b) Does the gravitational force do positive work or negative work?

(c) Is the total work done by both forces positive or negative?

Now, starting from a separation of D, charge q is moved to the left while charge Q is held fixed until the separation is $2D$.

(d) Is the work done by the electric force the same as or different than in (a)?

(e) Is the total work done by both forces the same as or different than in (c)?

Finally, starting from a separation of D, both charges are simultaneously released. Consider only the time interval from when the separation is D until the separation is $2D$.

(f) Is the total work done by the electric force the same as or different than in (a)?

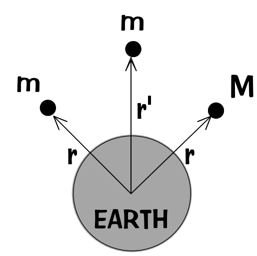
(g) Which of the charges has more total work done on it?

Reflection (continued)

R3. Suppose a charged object is interacting with other charged objects that have fixed positions. If released, will the original charged object always move so that the potential energy decreases?

R4. In part C, did you draw any sketches for situation C2? If so, what kinds of sketches did you draw? If not, why not?

R5. Reconsider situation C1, in which three point masses are positioned above the Earth as shown.



(a) What did you take as your system (or systems) to answer these questions? For instance, did you consider the Earth and the three point masses one isolated system, or did you consider each mass a separate system? If you did not explicitly define your systems, identify your implicit choices. On a copy of this figure, draw a dotted line around each system, and label them (1, 2, 3, etc.). Use these labels when you answer the following questions.

(b) What is the definition of the total energy (E_{total}) for your chosen system(s)? Be specific. For instance, is there any gravitational potential energy in your chosen system(s)? Which bodies contribute to the total kinetic energy of your system(s)?

(c) Are there any forces external to your system(s)? Do any of these external forces do work when the masses fall a distance d? Is the total external work (W_{ext}) positive, negative, or zero?

(d) What is the relationship between E_{total} and W_{ext}? What do we call this relationship? What is the conceptual basis of this relationship?

R6. Is it possible for a force to get smaller, yet the potential energy associated with it to get larger? Give at least 2 examples of situations in which this is true.

R7. Consider a space probe, launched from the Earth toward the farthest edge of the galaxy.

(a) Where is the probe when the Earth–probe system has the largest amount of gravitational potential energy? Explain why you think so.

(b) Does the Sun–probe system have any gravitational potential energy in it? Is it increasing or decreasing during the journey of the probe? Explain.