Science Education Collection

Energy and Work by Force

URL: https://www.jove.com/science-education/10313

Overview

Source: Asantha Cooray, PhD, Department of Physics & Astronomy, School of Physical Sciences, University of California, Irvine, CA

This experiment demonstrates the work-energy principle. Energy is one of the most important concepts in science and is not simple to define. This experiment will deal with two different kinds of energy: gravitational potential energy and translational kinetic energy. Gravitational potential energy is defined as the energy an object possesses because of its placement in a gravitational field. Objects that are high above the ground are said to have large gravitational potential energy. An object that is in motion from one location to another has translational kinetic energy. The most crucial aspect of energy is that the sum of all types of energy is conserved. In other words, the total energy of a system before and after any event may be transferred to different kinds of energy, wholly or partly, but the total energy will be the same before and after the event. This lab will demonstrate this conservation.

Energy can be defined as "the ability to do work," which relates mechanical energy with work. Flying projectiles that hit stationary objects do work on those stationary objects, such as a cannonball hitting a brick wall and breaking it apart or a hammer driving a nail in to a piece of wood. In all cases, there is a force exerted on a body, which subsequently undergoes displacement. An object in motion has the ability to do work, and thus it has energy. In this case, it is kinetic energy. In this experiment, gravity will be doing work on gliders.

The transfer of the potential energy of gravity to translational kinetic energy will be demonstrated in this experiment by sliding a glider down air tracks at various angles (*i.e.,* heights), starting from rest. The potential energy of an object is directly proportional to its height. The net work done on an object is equal to the change in its kinetic energy; here, the glider will start from rest and then gain kinetic energy. This change in kinetic energy will be equal to the work done by gravity and will vary depending upon the starting height of the glider. The work-energy principle will be verified by measuring the starting height and the final velocity of the glider.

Principles

Potential energy is associated with forces and is stored within an object. It depends upon the position of the object relative to its surroundings. An object raised off the ground has gravitational potential energy because of its position relative to the surface of the earth.This energy represents the ability to do work because, if the object is released, it will fall under the force of gravity and do work upon what ever it lands on. For instance,dropping a rock on a nai lwill do work on the nail by driving it into the ground.

Suppose an object is moving in a straight line at velocity v_0. To increase the velocity of the object up to v_1, a constant force F_{net} would need to be applied to the object. The work W done on an object by a constant force F is defined as the product of the magnitude of the displacement d multiplied by the component of the force parallel to the displacement, $F_{||}$

$W = F_{||}d$. **(Equation 1)**

In the case of the moving object, if the force is applied in the direction parallel to the motion of the object, then the net work is simply equal to the net force times the distance traveled:

$W = F_{net}d$. **(Equation 2)**

From kinematics, it is known that the final velocity of an object under constant acceleration is:

$v_1^2 = v_0^2 + 2ad$. **(Equation 3)**

Applying Newton's second law, $F_{net} = ma$, and solving for the acceleration in **Equation 3** gives:

$W_{net} = F_{net}\,d = mad = md(v_1^2 - v_0^2)/(2d) = (v_1^2 - v_0^2)/2$. **(Equation 4)**

Equivalently:

$W_{net} = ½\, m\, v_1^2 - ½\, m\, v_0^2$. **(Equation 5)**

If translational kinetic energy is defined as $KE = ½\, mv^2$, then this is just the work-energy principle: the net work done on a system is equal to the change in the kinetic energy of the system.

Now consider gravitational potential energy. If an object starting from a height h falls from rest under the influence of gravity, the final velocity of the object can be found using **Equation 3**

$v^2 = 2gh$. **(Equation 6)**

After falling from height h, the object has kinetic energy equal to $½\, mv^2 = ½\, m(2gh) = mgh$. This is the amount of work the object can do after falling a vertical distance h and is defined as the gravitational potential energy, PE:

$PE = mgh$, **(Equation 7)**

where g is the gravitational acceleration. The higher the object is placed above the ground, the more gravitational potential energy it has. Gravity is acting, or doing work, on the object, so in this scenario, $W_{net} = mgh$. From the work-energy principle, it is known that this gravitational potential energy should then be equal to the change in kinetic energy:

$½ mv^2 = mgh$. **(Equation 8)**

Procedure

1. Obtain an air supply, bumpers, two gliders of varying mass, a velocity sensor, an air track, an aluminum block, and a scale (see **Figure 1**).
2. Place the lower-mass glider on the scale and record its mass.
3. Connect the air supply to the glider track and turn it on.
4. Place the aluminum block under the glider stand,close to the air supply. This will be the lowest-height configuration.
5. Place the glider at the top of the track and measure the height, h_1. The measurement should be with respect toits approximate center of mass.
6. Place the glider at thebottom of the track and measure the lower height, h_0.The differenceh_1 - h_0 should be the height of the aluminum block, but perform the measurements to verify.
7. Place the glider back on the top of the track, just above the leg and aluminum block, and release it from rest. Record its velocity v at the bottom of the track using the timing gates. Ensure that the velocity is measured with respect to the point where h_0 was measured. Do this five times and take the average velocity. Record this velocity in the appropriate box in **Table 1**.
8. Place another aluminum block under the glider stand. This will add 3.4 cm to the potential energy calculation. Repeat step 1.7.
9. Fill in **Table 1**. Calculate KE and PE for each run and compute their differences.
10. Repeat steps 1.2-1.9 with the heavier glider.

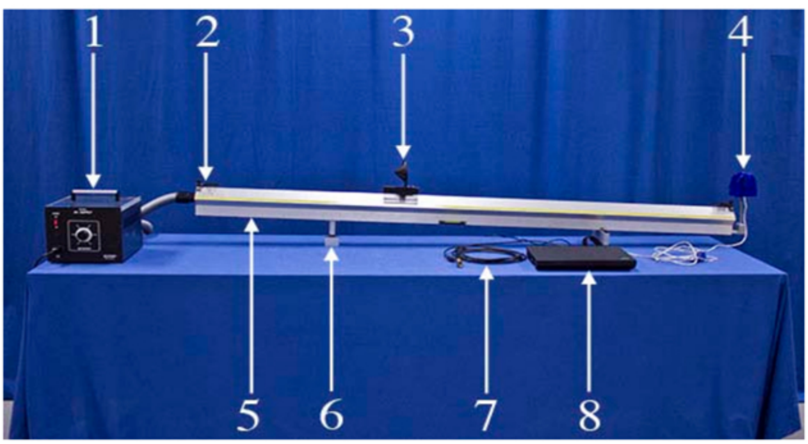

Figure 1: Experimental setup. The components include: (1) air supply, (2) bumper, (3) glider, (4) velocity sensor, (5) air track, and (6) aluminum block.

Results

Sample calculated values of the initial potential energy at various heights are listed in the PE column of **Table 1**, found using **Equation 7**. The final velocities measured from the experiment are also in the table. The translational kinetic energy is calculated using these measured values of the final velocity. According to the work-energy theorem, the KE and PE columns in the table should be equal, and they nearly are. The discrepancies in the two values simply come from errors in the measurements taken throughout the experiment, where a percent difference of around 10% can be expected from this type of experiment.

Note that as the initial height is increased, the final velocity also increases at a rate that is proportional to the square root of the height increase (c.f. **Equation 6).** The potential energy of the system also increases with increased height. Furthermore, note that the cart with the increased mass (the last three rows in **Table 1**) has both higher potential energy and kinetic energy when compared to the lower-mass cart (first three rows), but the final velocities of this cart are the same as for the lower-mass cart. This makes sense because the final velocity is only a function of the height (**Equation 6).**

Table 1: Results.

Cart Mass (kg)	Height (cm)	*PE* (mJ)	V_f (m/s)	*KE* (mJ)	% difference
0.23	3.4	77	0.8	74	4
0.23	6.8	155	1.2	167	8
0.33	3.4	111	0.85	120	8
0.33	6.8	221	1.25	259	17

Applications and Summary

Applications of the work-energy principle are ubiquitous. Roller coasters are a good example of this energy transfer. They pull you up to a great height and drop you down a steep incline. All the potential energy that you gain at the top of the incline is then converted to kinetic energy for the rest of the ride. The coasters are also massive, which adds to the potential energy. Skydivers use this principle as well. They ride in an airplane that does work on the system to bring them to a height of around 13,000 feet. Their initial velocity in the vertical direction is nearly zero just before they jump out, and they quickly reach terminal velocity (because of air resistance) after jumping. Firing a gun also converts potential energy to kinetic. The gunpowder in the ammunition has a lot of stored chemical potential energy. When it is ignited, it does work on the bullet, which exits the muzzle with a tremendous amount of kinetic energy.

The work-energy principle has been derived in this experiment. Using a glider on an inclined air track, the work done by gravitational force has been experimentally verified to equal the change in the kinetic energy of the system.