Potential and Kinetic Energy

Last lesson we began our journey to understanding energy. We discussed the fact that energy is the ability to do work. We defined work as moving an object over a distance against a force. We defined power as the amount of work done over time. We also, defined a few of the common energy units Joule, calorie, horsepower and Watt. We covered some confusing stuff, but don't feel bad if you're having trouble with it. It takes a while for this to sink in. This lesson we're going to talk about the two main categories of energy: potential and kinetic. We will talk about transfer of energy and we will also discuss conservation of energy and energy efficiency.

Potential and Kinetic Energy

All the different forms of energy (heat, electrical, nuclear, sound etc.) can be broken down into two categories, potential and kinetic energy.

My classes have nicknamed potential energy the "could" energy. The battery "could" power the flashlight. The light "could" turn on. I "could" make a sound. That ball "could" fall off the wall. That candy bar "could" give me energy. Potential energy is the energy that something has that can be released. For example, the battery has the potential energy to light the bulb of the flashlight if the flashlight is turned on and the energy is released from the battery. Your legs have the potential energy to make you hop up and down if you want to release that energy (like you do whenever it's time to do science!). The fuel in a gas tank has the potential energy to make the car move.

Kinetic energy is the energy of motion. Kinetic energy is an expression of the fact that a moving object can do work on anything it hits; it describes the amount of work the object could do as a result of its motion. Let's try to put that a little more simply. Remember from last lesson that work is the amount of distance something travels against a force. A Joule is the amount of energy it takes to exert one Newton the distance of a meter. Also, remember that a Newton is a unit of force. It takes about one Newton of force to lift an apple. So if something has 10 Joules of kinetic energy it can apply a force of one Newton over a distance of 10 meters. "Wow, thanks Jim, that's incredibly clear now, clear as mud!" Hmm, okay let's go a little further with that example. An arrow is shot from a bow and by the time it hits an apple it is traveling with 10 Joules of kinetic energy (kinetic energy is the energy of motion). What's meant by kinetic energy is that when it hits something, it can do that much work on whatever is hit. Soooo, back to the arrow, if the arrow hits that apple it can exert 10 Joules of energy on that apple. It takes about 1 Newton of force to move that apple so the arrow can move the apple 10 meters. One Joule equals one Newton x one meter so 10 Joules would equal one Newton x 10 meters. It could also exert a force of 10 Newton's over one meter or any other mathematical calculation you'd like to play with there. (This, by the way, is completely hypothetical. With the apple example we are conveniently ignoring a bunch of stuff like the fact that the arrow would actually pierce the apple, and that there's friction, heat, sound, and a variety of other forces and energies that would take place here.)

There's one specific type of potential energy that's worth spending some more time on. That's gravitational potential energy. Gravitational potential energy is the energy something has due to gravity. This is the physics version of "what goes up, must come down". If a ball is sitting on top of a book shelf, it has the potential to fall off. If the ball were to fall off the bookshelf it would potentially hit the floor with a certain amount of Joules of energy. The formula for this is potential energy = mass x gravity x height, or PE=mgh. Mass is the mass of the object, Gravity is the gravitational constant 10 m/s^2, and height is how high the object is above the ground. "Um, Jim, isn't the gravitational constant 32 ft/s^2?" Yes, you're right. The gravitational constant is how fast gravity accelerates things and we've generally been using 32 ft/s^2. However, since we're calculating Joules here, we need to use metric measurements. In metric the gravitation constant is 9.8 m/s^2. I tend to round that up to 10 m/s^2 to make the math a little simpler. So, let's say that a 1 kg ball is sitting on a 2 meter (about 6 feet) tall bookshelf. That ball has:
PE=mgh
PE= 1 kg x 10 m/s^2 x 2m
PE= 20 Joules

It has the potential to hit the floor with 20 Joules of energy.

Transfer of Energy

Now's a good time to introduce another concept here, transfer of energy. Energy changes to other forms of energy all the time. The electrical energy coming out of a wall socket transfers to light energy in the lamp. The chemical energy in a battery transfers to electrical energy which transfers to sound energy in your personal stereo. In the case of the ball falling, gravitational potential energy transfers to kinetic energy, the energy of motion.

The formula for kinetic energy is $^1/_2$ mass x velocity^2 or $KE = {}^1/_2 mv^2$.

Let's do an experiment at this point to make this clearer.

Experiment 1
Whackapow!

You need:
Several balls of different weights no bigger then the size of a baseball. Golf ball, racket ball, ping pong ball, marble etc.
Good size container or mixing bowl
Flour or corn starch or any kind of light powder
Tape measure or yard stick
Spring scale or kitchen scale

What you do:
1. Fill the container about 2 inches or so deep with the flour.

2. Weigh one of the balls (If you can, weigh it in grams).

3. Hold the ball about 3 feet (one meter) above the container with the flour.

4. Drop the ball.

5. Whackapow! Now take a look at how deep the ball went and how far the flour spread. (If all your balls are the same size but different weights it's worth it to measure the size of the splash and the depth the ball

went. If they are not, don't worry about it. The different sizes will effect the splash and depth erratically.

6. Calculate the gravitational potential energy of the ball. Take the mass of the ball, multiply it by 10 m/s^2 and multiply that by 1 meter. For example, if your ball had a mass of 70 grams (you need to convert that to kilograms so divide it by 1000 so that would be .07 grams) your calculation would be
PE=.07 x 10 x 1 = .7 Joules of potential energy.

7. Try it with different balls. Be sure to record the mass of each ball and calculate the potential energy for each ball.

Each one of the balls you dropped had a certain amount of potential energy that depended on the mass of the ball and the height it was dropped from. As the ball dropped the potential energy changed to kinetic energy until, "whackapow", the kinetic energy of the ball collided with and scattered the flour. The kinetic energy of the ball transferred kinetic energy and heat energy to the flour. So, how much kinetic energy did the ball in the example have the moment it impacted the flour. Well, if all the potential energy of the ball transfers to kinetic energy, the ball has .7 Joules of kinetic energy.

Conservation of Energy

The last experiment is an example of conservation of energy. Energy cannot be created or destroyed in a closed system. A closed system...what's that mean? In this case, a system is what's going on. The ball falling, is the system. A closed system means no energy can get in or out of the system. Within the closed system of the falling ball no energy is gained or lost in the entire system. Since that ball started with .7 Joules of energy, it hit the flour with .7 Joules of energy and transferred .7 Joules of energy to the flour. No energy was created or destroyed, just transferred. As the ball dropped it lost potential energy because it kept losing height. Also, as the ball dropped it gained kinetic energy because it kept gaining speed. So, when the potential energy was .7 the kinetic energy was 0 (not moving). When the kinetic energy was .7 the potential energy was 0 (no height). All the energy transfers during the fall.

Here's a great way to watch energy switch from potential energy to kinetic energy.

(This is the end of part 2 of the lecture. Please stop here and go to part 3 after this experiment.)

Experiment 2
Energy Flip Flop

You need:
String
Tape
A washer or a weight of some kind

What you do:

1. Make the string into a 2 foot or so length.

2. Tie the string to the washer, or weight.

3. Tape the other end of the string to a table.

4. Lift the weight and let go, causing the weight to swing back and forth at the end of the pendulum.

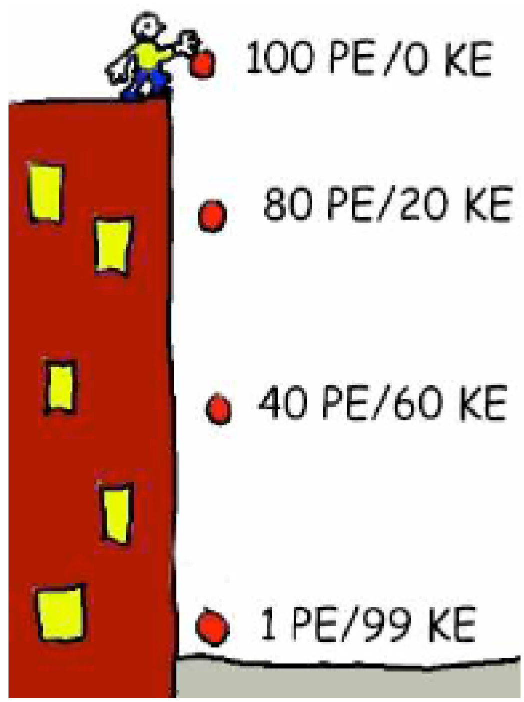
Watch the pendulum for a bit and describe what it's doing as far as energy goes. Where is the potential energy greatest? Where is the kinetic energy greatest? Where is potential energy lowest? Where is kinetic energy lowest? Where is KE increasing, and PE is decreasing? Where is PE increasing and KE decreasing? Where did the energy come from in the first place?
A video of this is available at www.handsonlinelearning.com/movies.

Remember, potential energy is highest where the weight is the highest. Kinetic energy is highest were the weight is moving the fastest. So potential energy is highest at the ends of the swings. Here's a coincidence, that's also where kinetic energy is the lowest since the weight is moving the least.

Where's potential energy the lowest? At the middle or lowest part of the swing. Another coincidence, this is where kinetic energy is the highest. Now, wait a minute...coincidence or physics? It's physics right? In fact, it's conservation of energy. No energy is created or destroyed, so as PE gets lower KE must get higher. As KE gets higher PE must get lower. It's the law...the law of conservation of energy! Lastly, where did the energy come from in the first place? It came from you. You added energy (increased PE) when you lifted the weight. (By the way, you did work on the weight by lifting it the distance you lifted it. You put a certain amount of Joules of energy into the pendulum system. Where did you get that energy? From your morning Wheaties!)

Conservation and Transfer of Energy

As Phillip holds the ball at the top of the building, the ball has 100 Joules of potential energy (the number is just an example). When he drops it, the potential energy of the ball drops since the height of the ball gets less and less. At the same time, however, kinetic energy increases because the speed of the ball increases. All the way down, the sum of the two energies equals 100. No energy gets lost, it only gets transferred. Energy is conserved.
A cartoon of this is available at www.handsonlinelearning.com/movies.



Energy Efficiency

Now here's a question you may be asking yourself, "If energy is neither created or destroyed in a closed system then why doesn't the pendulum go forever! Ahhh, that's a very intelligent question. You must be very smart! Energy is neither created or destroyed, but it can be transferred into non-useful energy. In the case of the pendulum, every swing loses a little bit of energy, which is why each swing goes slightly less high (achieves slightly less PE) than the swing before it. Where does that energy go? To heat. The second law of thermodynamics states basically that eventually all energy ends up as heat. If you could measure it you'd find that the string, and the weight have a slightly higher temperature then they did when they started due to friction. The energy of your pendulum is lost to heat! If you could prevent the loss of energy to useless energy you could create a perpetual motion machine. A machine that works forever!. There have been a lot of folks who have spent a lot of time trying to make a perpetual motion machine. So far, they have all failed. A perpetual motion machine is one that is said to be 100% energy efficient. In other words all the energy that goes into it goes to useful energy. Your pendulum could be said to be about 90% efficient. Very little energy is converted into useless energy. In most systems, energy is converted to useless heat and sound energy.

Experiment 3
Go Car Go

What you need:
A Few toy cars
Board, book or car track
Measuring tape

What you do:

1. Set up the track, board or book so that there's a nice slant to the floor.

2. Put a car on the track.

3. Let the car go.

4. Mark or measure how far it went.

As you lifted the car onto the track you gave the car potential energy. As the car went down the track and reached the floor the car lost potential energy and gained kinetic energy. When the car hit the floor it no longer had any potential energy only kinetic. If the car was 100% energy efficient, the car would keep going forever. It would never have any energy transferred to useless energy. Your cars didn't go forever did they? Nope, they stopped and some stopped before others. The ones that went farther were more energy efficient. Less of their energy was transferred to useless energy than the cars that went less far. Where did the energy go? To heat energy, created by the friction of the wheels, and to sound energy. Was energy lost? NOOOO, it was only changed. If you could capture the heat energy and the sound energy and add it to the the kinetic energy, the sum would be equal to the original amount of energy the car had when it was sitting on top of the ramp.

In a Nutshell

-Potential Energy is the amount of energy something can use to do work.

-Gravitational potential energy is the amount of energy something has due to its height above the ground. The higher it is and more mass it has the more gravitational potential energy it has. PE=mgh

-Kinetic energy is energy of motion. The faster something is moving and/or the more massive it is the more kinetic energy it has. KE= $^{1}/_{2}\ mv^{2}$

-Energy can be transferred, in other words it can be changed from one form to another and from one object to another.

-Conservation of energy means that in a closed system energy can neither be created or destroyed.

-Energy efficiency is how much energy in a system is transferred to useless energy. The most common forms of useless energy are sound energy and heat energy.

Did You Get it?

1. What is potential energy?

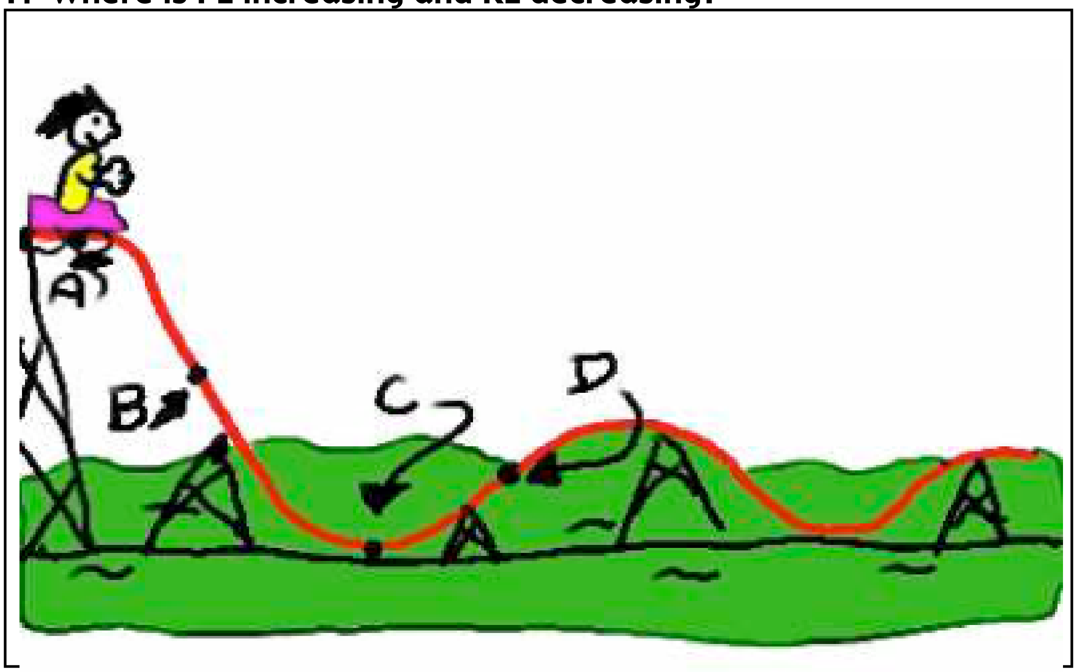
2. What is kinetic energy?

3. What is gravitational potential energy?

4. What does transfer of energy mean?

5. What is conservation of energy?

6. Describe the potential and kinetic energy of this roller coaster.
    - A. Where is the potential energy greatest?
    - B. Where is the kinetic energy greatest?
    - C. Where is potential energy lowest?
    - D. Where is kinetic energy lowest?
    - E. Where is KE increasing, and PE is decreasing?
    - F. Where is PE increasing and KE decreasing?



7. What's energy efficiency?

8. Which is more energy efficient, a nice new Hot Wheel car or one that's

been stepped on?

9. In most systems, where are the most common two sources of non-useful energy?

10. What is work?

11. What does a Newton measure?

12. What does a Joule measure?

Answers to Did You Get It

1. Potential energy is the energy that something has that can be released.

2. Kinetic energy is the energy of motion. $KE = {}^{1}/_{2}\ mv^2$

3. Gravitational potential energy is the energy something has due to gravity. Gravitational Potential Energy = mgh

4. Energy can be changed from one form to another and from one object to another.

5. In a closed system energy can neither be created or destroyed.

6. A. Potential energy is greatest at a. The coaster is at it's highest point above the ground.
B. Kinetic Energy is the greatest at c. The coaster is going the fastest at this point.
C. Potential energy is lowest at c. The coaster is as low as it can get.
D. Kinetic energy is lowest at a. The coaster is not moving.
E. KE is increasing and PE is decreasing at b. The coaster is losing height so it's losing PE but it is gaining speed so it is gaining KE.
F. PE is increasing and KE is decreasing at d. The coaster is getting higher so it's gaining PE but it's losing speed so it's losing KE.

7. Energy efficiency is how much energy in a system is transferred to

useless energy.

8. It depends on what you want the car to do! If you want the car to go far after leaving the track you want the brand new one. It will have less of the original potential energy transferred to heat since it will have less friction. However, if you want your car to generate heat, you want the stepped on one. It will have much more of its energy transferred to heat due to its high friction! (In other words, you need to be a bit careful with the term "useful" energy)

9. Sound energy and heat energy. Heat comes from the force of friction. Sound energy, as a matter of fact, also gets transferred to heat energy.

10. Work is defined as moving an object over a distance against a force. Work = force x distance

11. A Newton is a unit of force. How much force it takes to push or pull something. It takes about one Newton of force to lift an apple.

12. A Joule is a unit of energy. It takes one Joule to exert one Newton of force over a distance of one meter.

A Little Math

Gravitational Potential Energy PE=mgh: m is mass, g is $10 m/s^2$ ($32 ft/s^2$), and h is height.

1. Timmy is sitting 3 m (9 feet) up in a tree holding a 1 kg (about 2 pound) snowball. What's the gravitational potential energy of the snowball?

2. Susie is now standing under the tree. The distance between the snow ball and the top of Susie's head is 2 m. What's the potential energy of the snow ball if it was to be dropped on Susie's head?

3. What is the kinetic energy that the snowball has just before it hits Susie? (No math needed here, just think about it for a second.)

Kinetic energy = $^1/_2\ mv^2$ m is mass and v is velocity.

4. What is the kinetic energy of a 680 kg (1300 lb.) car traveling at 13 m/s (30 mph)?

5. What is the kinetic energy of a 680 kg car traveling at 26 m/s (60 mph)

Answers to A Little Math

1. PE = mgh
PE = 1 kg x 10 m/s^2 ft/s^2 x 3m
PE = 30 Joules

2. PE = mgh
PE = 1 kg x 10 m/s^2 x 2m
PE = 20 Joules (Don't worry, since the snowball falls apart very little of the energy actually gets transferred to poor Susie.)

3. 20 Joules. All the potential energy that the snowball started with becomes kinetic energy by the time it hits Susie.

4. KE = $^1/_2$ mv^2
KE = $^1/_2$ 680 kg x $(13m/s)^2$
KE = 340 kg x 169
KE = 57460 Joules (WOW!)

5. KE= $^1/_2$ mv^2
KE =$^1/_2$ 680 x 26^2
KE = 340 x 676
KE = 229,840 Joules (WOW WOW)

This is an important point. As the speed of something doubles, its kinetic energy squares! This is why it is very important to not speed in a car. An increase in speed quickly increases the potentially dangerous kinetic energy.