

Mission: What determines whether energy will transfer?

Age: 8+

Materials cost: \$5

Time: 25 min (Set-up: 5 min | Activity: 15 min | Clean-up: 5 min)

What you need:

Materials:

- Paper clips (same size)
- Washers or binder clips
- Yarn or string
- Tape

Equipment:

- Ruler
- Scissors
- Two dining room chairs (make sure not to sit on the chairs or to disturb them during the experiment.)

What to do:

1. Cut a 3-foot-long string (about hip to floor length). Tie or tape each end to the backs of two chairs and move them apart until the string is straight, but not pulled too tight.
2. Make a paperclip chain by hooking equal-sized paperclips together until it is about 8 inches long.
3. Weight the chain by adding washers or binder clips to the last paperclip. Count how many you use.
4. Hang the chain at the middle point of the string, with the weighted end hanging down.
5. Keeping the chain straight, pull the weight back until it is slightly lower than the string, then open your fingers and let it go. Observe how much time it takes to swing back and forth once.
 - A. Next, try changing the number of paperclips to see how the swing time is affected. What do you notice?
 - B. After testing several different lengths, return the chain to its original length.

6. Make a second identical chain and hang both on the string, using a ruler to place each of them an equal distance from each chair. (Make sure there is enough space between them so they don't accidentally hit while swinging.)
7. Pull back just one of the weighted chains (not both!) And let it swing, just like you did in Step 5. Watch what happens to the second chain!
8. Now shorten or lengthen just one of the chains (so that they are different lengths) and try it again. What happens to their swings this time? Why do you think that happens?
9. Keep experimenting!

Clean-up:

Remove the paperclip chains from the string. Take the washers off the chains and disassemble them. Undo the string from the chairs and discard it. Return the chairs to their original locations.

What's Happening?

The two paperclip chains act like pendulums, transferring their energy between one another through the string that connects them.

A pendulum is made by hanging an object on a string and attaching it securely at the top so it swings in a repeated motion, just like our paperclip chains. Initially, both chains are at rest. When one chain is pulled back and released, it swings at its natural frequency. As this chain swings, it tugs on the string giving a repeated "kick" to the stationary paperclip chain. The stationary paperclip chain receives this energy and begins to swing as well.

This energy transfer process is most efficient when the natural frequencies of both pendulums match each other. This is why identical pendulums display stop-and-go swinging while pendulums with different lengths or masses do not. You can tell that energy has been fully transferred to the second chain when the one that was originally set in motion stops completely while the second chain is in full swing.

When natural frequencies differ, only partial energy transfer is possible. The two chains will continue to transfer energy back-and-forth until the energy of their movement eventually gets lost through the string, chairs, and tape that connect them.

Pendulums are a great model for understanding energy transfer because processes in nature and the world around us utilize natural frequencies all the time, and when natural frequencies match, interesting and amazing things happen!

So What?

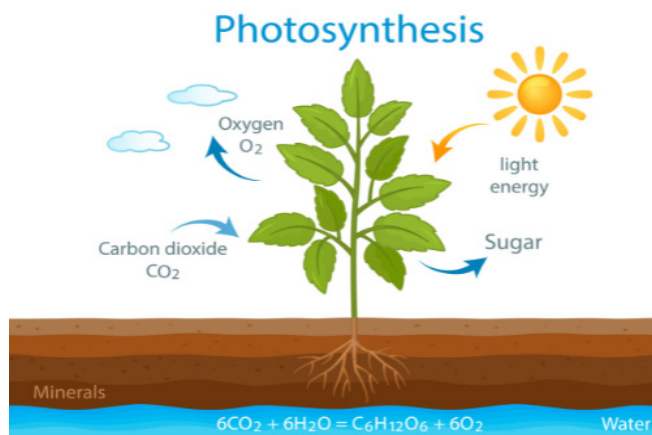


Image credit: Adobe Stock

Energy comes in many different forms such as light, heat, electricity, chemical bonds, and motion (like in a pendulum...or a moving car). Scientists have learned that the energy in our world can not be created or destroyed, it simply changes forms through energy exchanges. Since we need energy in particular forms for different purposes, it is important to learn how to efficiently convert it to the kinds we need. The behavior of pendulums provides an important clue!

Nature is full of examples of efficient energy exchanges caused by natural frequencies that match! Since the natural frequency of an object or material is determined by how it is structured, material scientists observe energy exchanges to help create new material structures or use existing materials to help solve important problems.

Killing cancer cells by using the energy exchange between light and gold nanoparticles is one example. Like a pendulum, every wavelength of light has its own natural frequency. Similarly, the way in which gold atoms fit together in a tiny nanoparticle makes them vibrate at their own natural frequency, too. Therefore, when doctors strategically place gold nanoparticles inside a cancerous tumor and shine a strong light beam that matches the natural frequency of the gold, the light energy transfers to the gold, making it vibrate! Meanwhile, the light itself does not harm the tissue because the tissue's natural frequency is not a match. These vibrations in the gold particle generate a lot of heat energy, though, and this heat kills the cancer cells around it!

Photosynthesis in plants is another example in nature where many efficient energy exchanges in a row convert the sun's light energy into the energy-rich plant food that living beings need to eat for survival. During the process, carbon dioxide from the air is captured and is replaced with fresh oxygen that we need to breathe, too. So there are multiple good things happening!

NGSS Alignment of Energy Exchange Activity

The information below may not include every area that this activity can be linked to NGSS concepts

Disciplinary Core Ideas

PS2.A: Forces and Motion

- **Grade 3**

- ◇ Each force acts on one particular object and has both strength and a direction.

- **Middle School**

- ◇ The motion of an object is determined by the sum of the forces acting on it; if the total force on the object is not zero, its motion will change. The greater the mass of the object, a larger force causes a larger change in motion.
- ◇ All positions of objects and the directions of forces and motions must be described in an arbitrarily chosen reference from and arbitrarily chosen units of size.

PS2.B: Types of Interactions

- **Grade 3**

- ◇ Objects in contact exert forces on each other.

- **Middle School**

- ◇ Gravitational forces are always attractive. There is a gravitational force between any two masses, but it is very small except when one or both of the objects have a large mass.
- ◇ Forces that act at a distance can be explained by fields that extend through space and can be mapped by their effect on a test object.

PS3.A: Definitions of Energy

- **Grade 4**

- ◇ The faster a given object is moving; the more energy it possesses.
- ◇ Energy is present whenever there are moving objects, sound, light, or heat. When objects collide, energy can be transferred from one object to another, thereby changing their motion.

PS3.B: Conservation of Energy and Energy Transfer

- **Grade 4**

- ◇ Energy is present whenever there are moving objects, sound, light or heat.

- **Middle School**

- ◇ When the motion of energy of an object changes, there is inevitably some other change in energy at the same time.

PS3.D: Energy in Chemical Processes and Everyday Life

- **Grade 4**

- ◇ The expression “produce energy” typically refers to the conversion of stored energy into a desired form for practical use.

PS4.A: Wave Properties

- **Middle School**

- ◇ A simple wave has a repeating pattern with a specific wavelength, frequency, and amplitude.

ETS1.A: Defining Engineering Problems

- **Middle School**

- ◇ Possible solutions to a problem are limited by available materials and resources.

Performance Expectations

2-PS2-1 Plan and conduct an investigation to provide evidence of the effects of balanced and unbalanced forces on the motion of an object.

3-PS2-2 Make observations and/or measurements of an object's motion to provide evidence that a pattern can be used to predict future motion.

3-5-ETS1-3 Plan and carry out fair tests in which variables are controlled and failure points are considered to identify aspects of a model or prototype that can be improved.

4-PS3-1 Use evidence to construct an explanation relating the speed of an object to the energy of that object.

4-PS3-2 Make observations to provide evidence that energy can be transferred from place to place by sound, light, heat, and electric currents.

4-PS3-3 Ask questions and predict outcomes about the changes in energy that occur when objects collide.

4-PS3-4 Apply scientific ideas to design, test, and refine a device that converts energy from one form to another.

MS-PS2-2 Plan an investigation to provide evidence that change in an object's motion depends on the sum of the forces on the object and the mass of the object.

MS-PS2-4 Construct and present arguments using evidence to support the claim that gravitational interactions are attractive and depend on the masses of interacting objects.

MS-PS2-5 Conduct an investigation and evaluate the experimental design to provide evidence that fields exist between objects exerting forces on each other even though the objects are not in contact.

MS-PS3-5 Construct, use, and present arguments to support the claim that when the kinetic energy of an object changes, energy is transferred to or from the object.

Crosscutting Concepts:

Patterns

- Grade 3
 - ◇ Patterns of change can be used to make predictions.

Cause and Effect

- Grade 3
 - ◇ Cause and effect relationships are routinely identified.
- Middle School
 - ◇ Cause and effect relationships may be used to predict phenomena in natural or designed systems.

Energy and Matter

- Grade 4
 - ◇ Energy can be transferred in various ways between objects.
- Middle School
 - ◇ Energy may take different forms.

Crosscutting Concepts:

Influence of Science, Engineering and Technology on Society and the Natural World

- Grade 4
 - ◇ Engineers improve existing technologies or develop new ones.

Stability and Change

- Middle School
 - ◇ Explanations of stability and change in natural or designed systems can be constructed by examining the changes over time and forces at different scales.

Systems and System Models

- Middle School
 - ◇ Models can be used to represent systems and their interactions - such as inputs, processes, and outputs, and energy and matter flows within systems.

Engineering and Science Practices

Planning and Carrying Out Investigations

- Grade 3-5
 - ◇ Plan and conduct an investigation collaboratively to produce data to serve as the basis for evidence, using fair tests in which variables are controlled and the number of trials are considered.
 - ◇ Make observations and/or measurements to produce data to serve as the basis for evidence for an explanation of a phenomenon or test a design solution.
- Middle School
 - ◇ Plan an investigation individually and collaboratively, and in the design: identify independent and dependent variables and controls, what tools are needed to do the gathering, how measurements will be recorded, and how much data are needed to support a claim.

Constructing Explanations and Designing Solutions

- Grade 3-5
 - ◇ Apply scientific ideas to solve design problems.

Developing and Using Models

- Middle School
 - ◇ Develop a model to describe the unobservable and mechanisms.