Forms of Energy: Single Transformations : Teacher Notes

Introduction

The focus of the investigation is to further define energy and to realize that one form of energy can be converted into another. The VolatgeCurrent and Temperature probes enable students to investigate quantitatively and measure the conversion of one form of energy into another. This investigation allows students to develop descriptions, explanations, predictions, and models using scientific evidence.

In addition, students will gain experience with inquiry skills, including:

- realizing that heat (energy) moves in predictable ways, flowing from warmer objects to cooler ones, until both reach the same temperature;
- knowing that electrical circuits provide a means of transferring electrical energy when heat, light, sound, and chemical changes are produced;
- identifying variables that can affect the outcome of an experiment;
- understanding that energy is a property of many substances and is associated with heat, light, electricity, mechanical motion, sound, nuclei, and the nature of a chemical. Energy is transferred in many ways;
- knowing that scientific investigations involve asking and answering a question;
- establishing relationships based on evidence and logical argument (e.g., provides causes for effects);
- knowing that scientific inquiry includes evaluating results of scientific investigations, experiments, observations, theoretical and mathematical models, and explanations proposed by other scientists (e.g., reviewing experimental procedures, examining evidence, identifying faulty reasoning, identifying statements that go beyond the evidence, suggesting alternative explanations).

Discussion Guide

Using this Guide

This guide is designed to help you convert the investigations your students experience into solid learning. The "Overview" section mentions some of the learning issues raised by this content. These issues might come up in conversations with students anytime. The "Setting the Stage" section provides ideas for a discussion you might hold before beginning the investigations. This discussion is important to motivate and alert students to observations that might answer their questions. The "Wrap Up" section can be used after the investigations to help student reflect on what they have done. Taking time to reflect while the investigations are fresh in students' minds has been shown to substantially increase learning.

Overview

The importance of energy is that it can be transformed from one form to another. This investigation demonstrates several common energy transformations. Of course, students have already seen some energy transformations in earlier investigations, so this investigation is actually designed to increase the range of transformations with which students are familiar.

This investigation introduces the idea that energy can be found in many places. In light, a capacitor, motion, heat, and sugar. One of the questions this raises is what defines energy. The easiest way to know if something has energy is to find a way to transform it into heat energy. If you can heat up the heat cell, then you had energy. In other words, energy is the ability to heat. This is a good definition, because all forms of energy can be transformed into heat energy. That's why transformations are important and why we explored heat energy first.

There is another advantage in being able to convert any form of energy into heat energy: it is always 100% efficient. For instance, when you use electricity to heat the heat cell, all the electrical energy is transformed into heat. In the experiment that uses light to heat the heat cell, all the energy in the absorbed light is converted into heat.

Students may have heard that "Energy is the ability to do work." This is correct in most situations, but it is useless unless you have a clear understanding of the technical meaning of work. Since students will not understand this, it would be best to avoid this formulation of energy. In case it comes up, you should know that "work" means force times the distance over which the force is applied.

The first trial in this investigation introduces an interesting new device, called a capacitor. A capacitor stores charge, so it provides a way of storing electrical energy. This is a lot like a rechargeable battery. The capacitor used has the capacity of one farad, which is huge. This is a million to a billion times the capacity of most capacitors found in electrical circuits.

It really is not important to describe how a capacitor works. Treat it as a "black box" in which electrical charge can be stored. The first activity gives students a "feel" for this. They can experience how it becomes more and more difficult to crank electricity into the capacitor as it fills up. They also see that a charged capacitor can turn the generator. This means that the energy they cranked into the capacitor can be converted into mechanical energy. They can also use the voltage and current probes to measure the flows of electrical energy in and out of the capacitor.

Your capacitor is big but fragile. It can be ruined two ways.

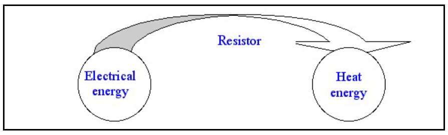
It will die if you put too much charge in it. Never put more than 5 volts across it. It will also die if you connect it backwards. Always connect positive voltage to the plus (+) terminal. This terminal is clearly marked on the capacitor.

Setting the Stage

Start this investigation by challenging students to illustrate as many different energy transformations as possible. Ask them to show each energy form as a labeled circle. The label in the circle should be a form of energy, not an example. This means that "kinetic energy" is allowed, but not "moving bicycle" which is an example of kinetic energy.

Connect the circles with arrows. Label the arrows with one device that causes the transformation. Students end up with a mesh of arrows and circles that looks like a concept map.

Here is an example:



Encourage debate among the students about these diagrams but avoid calling them right or wrong. Instead, ask students to save these for review at the end of the investigation.

Since few students will have ever seen a capacitor, introduce it before beginning the trials. Tell them that it stores electrical energy. Ask:

[Its energy could be converted to another form.] [Heat up the heat cell. Run the propeller. Run your radio.]

Warn student that the capacitor can be ruined if it are overloaded.

Wrap Up

After the trials, ask students working in groups to review the energy transformation drawings they made at the beginning of the investigation. Ask them to look for errors and additions. As these are presented to the class, have one student make a master diagram on the board.

As students present their ideas about energy transformations you may note some mistakes or statements that you are not sure of. Instead of trying to point out errors, ask for evidence or examples for every transformation. Ask what experiments in the investigation support each transformation.

The following are the most important transformations from this and previous investigations together with an example of each.

Potential energy --> kinetic energy. [Bike speeding up as it goes down a hill.]

Kinetic energy --> potential energy. [A bike coasting up a hill and slowing down.] Kinetic energy --> heat energy. [Using the breaks on a bike to slow you down.] Potential energy --> heat energy. [Using the breaks on a bike to maintain the same speed as you go downhill.] Electrical energy --> heat energy. [The propeller motor; any electrical motor.] Light --> heat energy. [Light shining on the heat cell; almost all cases where light is absorbed.] Chemical energy --> electrical energy. [Turning the generator by hand, using energy made chemically in your muscle.]

Students might be unsure about what energy turned the hand generator. It is simplest to think of the generator and crank as a mechanism for converting the chemical energy the powers your muscles into electricity. The chemicals are sugar and oxygen that you muscles use to generate a force while producing carbon dioxide and water.

We didn't emphasize the following, but students did experience these in the investigations:

Chemical energy --> electrical energy. [The battery that ran the propeller's motor.] Heat energy --> light. [The filament of the lamp.] Electrical energy --> electrical energy. [The capacitor. Here electrical energy of one kind, current and voltage, was transformed into another kind, charge in a capacitor.]

Here are some other transformations that students might come up with, but were not included in these investigations:

Heat energy --> kinetic energy. [Steam engine or turbine. This is the essential step in any power plant, whether the heat energy is supplied by coal, oil, or nuclear fission.] Electrical energy --> chemical energy. [Charging a battery.] Chemical energy --> kinetic energy. [Rocket engine. You could argue that the rocket fuel is converted to heat energy in the form of hot gasses and this is converted into kinetic energy.] Nuclear energy --> heat energy. [Nuclear power plant.] Light --> chemical energy. [Photosynthesis, the production of sugar in leaves.] Light --> electrical energy. [Solar cell.]

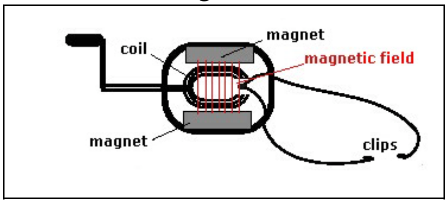
The following are very unusual transformations that are included here just in case they come up.

Chemical energy --> Light. [Light sticks, fireflies, glow worms.] Chemical energy --> Electrical energy. [Fuel cells. Electric eel.] Chemical energy --> Potential energy. [Muscle. A car engine climbing a hill.]

Gravity is not a form of energy. A capacitor is not a form of energy, although it can store electrical energy. Microwaves are a form of electromagnetic waves, as are light and radio waves. All forms of electromagnetic waves carry energy at the speed of light. A klystron converts electrical energy into microwaves to cook your food.

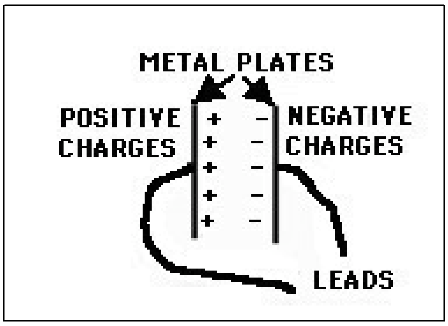
Additional Teacher Background

A generator works on the principle that when a wire is moved through a magnetic field, as a result current is produced in the wire. In the Genecon, a coil of wire is whirled around between two magnets, and current is produced in the coil. The faster you turn the coil, the more current is produced. For the current to flow, the two clips must be attached to something that completes the circuit, forming a loop for the current to flow through. This could be a light bulb, a heater, a motor, or a capacitor.



A motor is a generator working in reverse. When a current is run through the coils of the Genecon, a force is exerted on each wire. This makes the handle spin. In a generator, spinning creates a current. In a motor, current creates spinning. Motors and generators of varying sizes work on this same principle.

A capacitor is a device that stores electrical charges. In the simplest capacitor, two metal plates facing each other collect opposite charges, which are pushed there by a generator or a battery. This takes work to do, because the positive charges repel each other, and the negative charges do the same. This work is the same as the energy added to the capacitor. As the capacitor becomes charged, adding more charge gets harder and harder. The energy graph of the input should be steep at first and then level off, indicating that no more energy can be added.



When the leads of the charged capacitor are connected across something, such as a motor, the charges flow until the capacitor is neutral again, and the energy is given back to the motor.

The energy in a charged capacitor is electrical potential energy. This is analogous to the gravitational potential energy in the Potential and Kinetic Energy investigation. One could think of a capacitor as being like a water tower, where water can be pumped up high into the water tower and then flows downward and can be converted to some other form of energy. In the case of the water tower, the energy depends on the force of gravity. In the case of the capacitor, it depends on electrical forces between the charges.

In reality there are no moving "positive" charges. Negatively charged electrons travel in a wire. A surplus of electrons creates a net negative charge, and a shortage of electrons creates a net positive charge. The diagram above is a common way to represent this situation.

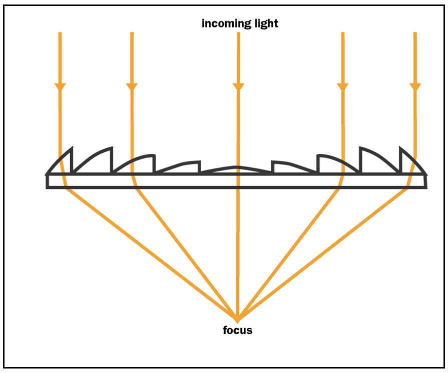
Capacitors, with their ability to store electrical energy and release it very fast, have many uses. A familiar one is the flash on a camera. A very small amount of energy is released so fast that it makes a bright, but brief, light. When one tries to run a motor with a capacitor, however, it won't work well. The energy will all come out quickly, and in this case the total amount of energy is small. So the air cart motor won't run very long. A battery, which stores electrical potential energy in chemical form, has a slower, steadier output.

Stored electrical energy can also be used to heat things. The heat cell is a resistor inside a block of aluminum. As the capacitor discharges, the electrons flow through the resistor and hit molecules along the way. This makes them move around with more energy, and the temperature rises. This change will be small but detectable using the heat cell and the Temperature probe.

The heat cell can also be warmed with sunlight. Light photons striking the aluminum are absorbed and give their energy to the aluminum atoms. A black surface will absorb more photons than a light or shiny surface, so it will heat up faster.

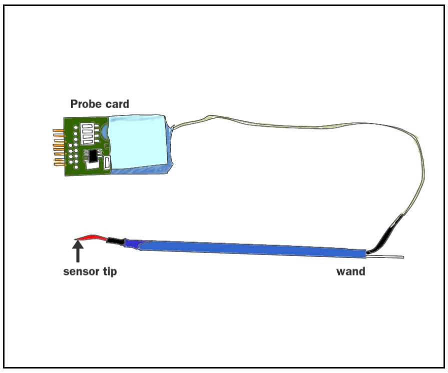
By focusing the sunlight, dramatic heating can be observed. The Fresnel lens is a special way of making a lens with a minimal amount of thickness. It was originally devised for the enormous glass lenses in lighthouses, which were both beautiful and extremely useful, because a small light source could be focused and seen from far away. (See, for example, http://acept.la.asu.edu/PiN/rdg/fresnel/fresnel.shtml and http://lighthousegetaway.com/lights/fresnel.html.)

The little plastic lens in the kit does the same thing, for less than $0.50! It consists of a series of concentric rings. One side is smooth and the other side is steeper as the distance from the center increases. Light bends (refracts) as it enters and leaves the plastic, because the speed of light is less in plastic than in air. The steeper the face of the ring, the more the light bends. So the light farthest from the center bends the most, and all the light rays come to the same focus.

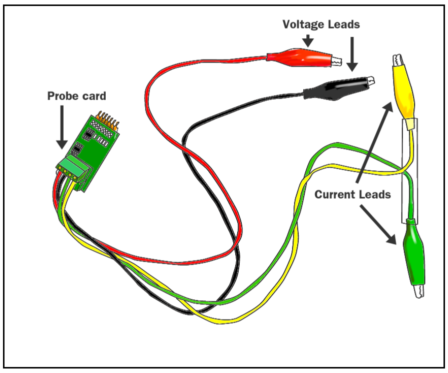


Sunlight has a lot of energy, but it is spread out thinly. A lens concentrates it from a larger to a smaller area, magnifying its heating effect. Students could explore the ratios involved, such as the area of the Fresnel lens compared to the area of the focused light on the heat cell. Strong sunlight has about 0.1 watts per square centimeter, so one side of the heat cell facing the sun receives less than 0.3 watts. The Fresnel lens, however, collects about 3 watts of power or 3 joules/second, ten times as much because it has ten times the area. This should cause a temperature rise in the heat cell of 0.3 degree C/second, because it takes 10 joules to raise the heat cell one degree. Students can look at the slope of their temperature graph and compare it to this "ideal" energy rate.

The Fast Response Temperature Probe uses a thermocouple to measure temperature. A thermocouple a made from two special wires, each of a different metal, with their ends twisted together or welded. When the temperature of that joint is different from the temperature of the other ends of the wires, a slight but highly predictable voltage is created. It comes from the way the two metals interact. Thermocouples are useful because they can work at very high temperatures. The CC Temperature probe can be put in a candle flame without damage.

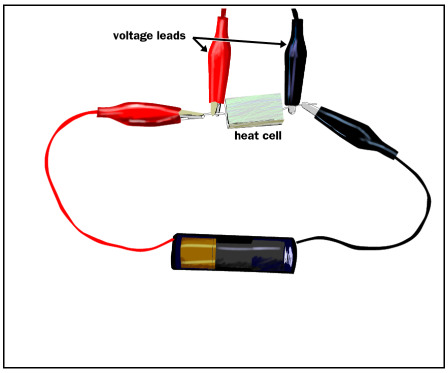


The only sensitive part is the tip where two special bare wires are twisted together. The wires produce a voltage depending on the temperature, and the CCProbe software converts this to degrees (C or F). The response is very fast, because the two wires are small and easily heated or cooled by whatever they touch.



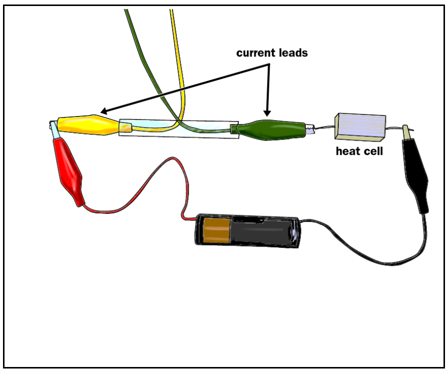
The Voltage/Current Probe measures either voltage or current. It can also measure both at the same time. The CCProbe software can use these readings to calculate and display power (watts) and energy (joules).

Voltage is like potential energy, The voltage between points A and B is a measure of the energy each electron could release as it moves from point A to point B in a wire. Voltage at one place is always measured relative to some other place. Therefore the probe requires two leads, and the voltage can be measured just by touching the two leads to two places. Voltage difference is measured in volts (V). The red clip lead goes to the greater, or positive (+) location, and the black clip lead goes to the smaller, or negative (-) location. To measure voltage across a heat cell , the clips are placed on the two ends of the heat cell as shown.



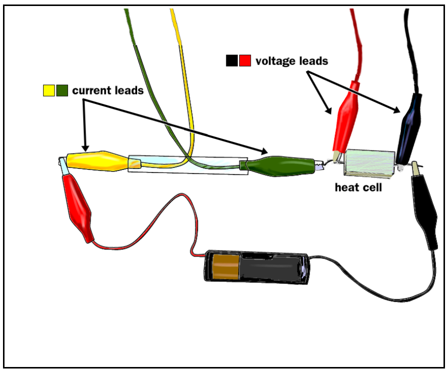
Current is the amount of electricity flowing, a bit like the current in a stream. Current can be pictured as the total number of electrons flowing per second through a wire or other substance. You can imagine measuring current by setting up a tollbooth in a wire and simply counting how many electrons went by each second. Current is measured in amperes (A).

To measure the current in a wire, you have to set up a tollbooth by breaking the wire and forcing the current to go through your current probe. The convention is that current is positive when it flows from a positive to a negative voltage, that is, from red to black. For the current through the probe to be positive, it should flow into the yellow clip lead and out of the green clip lead. Here is how to measure current going through a heat cell attached to a battery. Note: positioning of the probe is different while measuring current then it when measuring voltage.



Electrical power, the rate of using energy, is the voltage difference times current. It can be pictured as the number of electrons flowing per second, multiplied by the energy each one loses (P=IV). Power is measured in watts (W).

To measure the power going into a heat cell from a battery, you must measure both voltage and current. The CCProbeware will calculate and display the power from these measurements.



Electrical energy is the power accumulated over time. It can be pictured as the total number of electrons that flow, multiplied by the energy that each one gains (or loses). Energy is measured in joules (J). To measure the energy transferred into a heat cell from a battery, you must measure both voltage and current (see diagram above). The CCProbeware will calculate and display the energy from these measurements.

Depending on your needs, the Voltage/Current probe can be a volt meter, an ammeter, a power meter, or a joule meter!

Suggested Timeline

The amount of time you spend on introductory discussions, data collection, and analysis, will determine your overall timeline. The following represents a possible timeline.

One class period - "Setting Up" discussion

One class period - Trial I: Storing electrical energy

One class period - Trial II: Using stored electrical energy

One class period - Trial III: Heating with sunlight

One class period - Analysis and "Wrap Up" discussion

Additional days can be used for Further Investigations.

