Heating with Electricity : Teacher Notes

Introduction

The focus of the investigation is the conversion of electrical energy into heat energy. The VoltageCurrent and Temperature probes enable students to investigate quantitatively and measure the changing amount of heat energy on a heat cell or mini light when connected to an electrical source. 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;
- planning and conducting simple investigations (e.g., formulating hypotheses, designing and executing investigations, interprets data, synthesizing evidence into explanations, proposing alternative explanations for observations, critiquing explanations and procedures);
- 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

This investigation introduces electricity and the energy associated with it. This is hard for kids, because you cannot see electricity directly and we cannot measure its energy directly. This unit uses a hand crank to generate electricity, because students can feel the energy they need to exert to generate electricity. This provides an experiential basis for understanding electricity and electrical energy.

Electrical energy can be converted into heat energy easily and with 100% efficiency. This provides a way to relate this unit to the one on heat flow. This trick of converting electrical to heat energy is done with a resistor mounted in the heat cell. Making this connection between the two forms of energy should help dispel some of the mystery surrounding electrical energy.

This unit also introduces a way of measuring electrical energy flow directly with the voltage and current probe. Although it is a black box, by using the probe to measure energy created by hand turning the generator, students get a good idea of what it is measuring.

Two properties are used with electricity that are easily confused: current and voltage. Current is the amount of electricity flowing, a bit like the current in a stream. Current can be though of as the total number of electrons flowing per second through a wire or through a substance. You can imagine measuring current by setting up a tollbooth in a wire and simply counting how many electrons went through 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. This makes measuring current a pain; you have to disrupt the circuit to insert the current probe.

Voltage is like potential energy; in fact it is called electrical potential. The voltage between points A and B is a measure of the energy each electron could release if it went from A to B. It makes no sense to state the voltage at A; voltage at one place is always measured relative to some other place, just like PE. For instance, if you say that you have a 9 volt battery, you mean that the energy released per electron that flows from one terminal to the other of this battery is 9 volts.

Voltage difference is measured in volts (V). The probe requires two leads because voltage is always the potential for energy release between two points. Voltage can be measured just by touching the two leads to two places.

Electrical energy requires both current and voltage. If you have current flowing but no voltage difference, then no energy is being transmitted. This actually happens in superconductors. Huge currents can flow with no voltage drop. If there is a voltage drop but no current, then no energy is moving. A disconnected battery is a common example of this.

The rate at which energy moves is called power. Electrical power (P) is simply the product of current (I) and voltage difference (V):

$P = IV$

This formula captures the idea that if there is no current (I=0) or no voltage difference (V=0), then no energy is moving. Power measures the flow of energy. This unit uses a probe for power. The probe actually measures both current and voltage and the computer multiplies these to get power. Four connections are needed: two for the current and two for the voltage.

Power is not exactly energy, it is the rate of energy flow. In the unit, students can use a probe to measure the electrical power and the heating it causes. Electrical power causes the heat cell to warm. The more power that is added, the faster it will warm. Students will see this as the slope of the temperature graph for the heat cell. The harder they crank, the more power will be generated and the steeper the temperature will rise.

If students crank at a constant speed, the power, or rate of energy transfer, is constant. The total electrical energy they generate is equal to the power times the time they crank. They can also compute the added thermal energy by multiplying the heat cell's temperature rise by ten. Is the electrical energy generated the same as the thermal energy delivered to the heat cell? It should be, within experimental error.

Setting the Stage

Stimulate a discussion that reveals and begins to organize what students already know about electrical energy. Ask: [Electrical heaters, computers. In fact, every operating electrical device generates some heat.] [Power plants create electrical energy by turning generator, which is like a motor in reverse. The energy to turn the generator is provided by the potential energy of water behind the dam.] [Coal, oil, or nuclear energy is used to heat steam that turns a turbine that runs a generator.]

Point out that the electrical generators are just like the hand-cranked generators used in this unit. Challenge students to show that:

[This can be seen by cranking the generators with nothing connected.] [Connect a lamp across the generator's leads. You can see energy release by the light and feel the extra drag this makes. To see this most clearly, disconnect a wire while cranking--it instantly becomes easier.] [Attach the generators in pairs so that cranking one turns the other.]

Wrap Up

Stimulate reflection by reviewing the three trials and asking for each investigation: [Be sure students include the rotational kinetic energy of the generator, chemical energy in the battery, and light energy coming from the lamp.] Ask students to think carefully about the last trial. [Nothing, there is a vacuum inside.] [Not easily. A vacuum is a perfect insulator. I tiny bit of heat can move down the filament's wires to the base of the bulb and then up the glass.] [By light made from the white-hot filament and absorbed in the probe.] [Sure, warming by sunlight or bright lamps.] [No. The probe is tiny and very easy to warm up. Only a tiny bit of light energy suffices.]

Additional Teacher Background

To understand how electricity heats things, one needs to how electricity flows through materials. All common materials are made up of atoms. Each atom has equal numbers of positively charged protons, which are tightly bound together in a nucleus, and negatively charged electrons which surround the nucleus in a sort of cloud. Since the number of protons is equal to the number of electrons in a neutral atom, their charges cancel each other and the net charge of the atom is zero. The electrons are strongly attracted to the protons in the nucleus and can not stray far from it.

Electrical current is the flow of charges, usually the negatively charge electrons, through a material. When a voltage difference is applied, such as when a battery is attached to two ends of a wire, an electrical force is exerted on every electron. The electrons drift away from the negative pole and toward the positive pole. Individual electrons may not move very much, but the net effect is an electrical current.

In insulating materials that do not conduct electricity, there are almost no charges that are free to move. Metals such as copper, aluminum, and iron can conduct because some of the electrons are free to move around. Semi-conductors, special materials used for electronic circuits, are in between the two extremes. When a voltage difference is applied to a wire, the electrons are accelerated, and they hit the atoms in the metal. It's like someone trying to run through a crowd and knocking people this way and that. This makes the atoms vibrate or wiggle around, which results in heat energy in the material. As a result, the temperature of the material rises. It's like friction, except instead of the atoms being agitated by two surfaces rubbing together, they are agitated by the motion of the electrons.

Electrical resistors are designed to "resist" the flow of electrical current. The greater the resistance, the harder it is for current to flow freely. The energy that it takes to make the current flow is all converted into heat energy. Whenever electricity flows through normal materials, some of the energy is lost as heat. Sometimes this is desirable, as with electrical heating elements. Sometimes it is a waste, as with power lines.

The heat cell consists of a 10 ohm resistor in the center of a block of aluminum. Current flowing through the resistor heats it up, and the heat spreads throughout the whole aluminum block. Because aluminum conducts heat extremely well, the resistor and the aluminum stay at almost the same temperature. The little foam box reduces heat loss to the surroundings.

The electrical energy flowing into the heat cell and being converted to heat can be measured by hooking it to the Voltage/Current probe and plotting energy or power. It can also be measured by monitoring the change in temperature of the heat cell with the Temperature probe. Since changes in temperature are proportional to changes in heat energy of the heat cell, the temperature graph looks like a graph of the heat energy.

The amount of aluminum is such that it takes exactly 10 joules of energy to raise the temperature of the heat cell 1 degree Celsius. The slope of this graph is the rate of energy transfer, or power.

If the heat cell, without insulation, is connected to the Genecon that is cranked for

30s. The graph would look like this:

If the cranking rate is constant, the heating portion of the graph is a straight line with a positive slope. The power input (the slope of the line) is constant.

In this example, the temperature change is about (29.5 degrees C - 22 degrees C) = 7.5 degrees C, so the energy transfer is 75 joules. This takes about 30s, so the energy gain per second would be 75 joules/30s or 2.5joules/s or 2.5 watts, which is the power the Genecon is producing. Once the Genecon is no longer cranked, the heat cell loses heat to the environment and slowly cools down. The slope is negative, which means the power input is negative and energy is being lost. In this example, the rate of loss is about 1.5 degrees C/50s or 15 joules/50s or 0.3 joules/s or 0.3 watts.

If the heat cell is connected to a battery, a similar graph will be obtained. Inside a battery, chemical reactions push electrons toward the negative pole and away from the positive pole. When a wire is connected across the poles of the battery, the electrons flow through the wire and make a current.

These measurements present a good chance to explore the difference between power and energy. Energy, whatever form it takes, is constant in amount. It cannot be created or destroyed. It is measured in joules (J). Power is the rate of energy gained in a given amount of time. It is measured in joules per second (J/s), which is the same as watts (W).

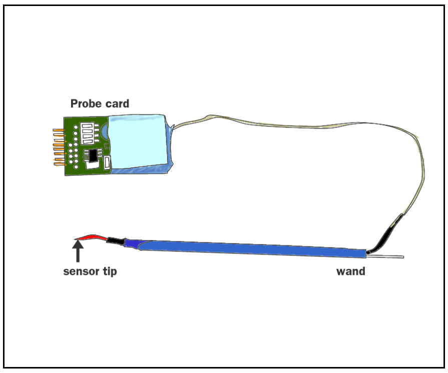
There are many situations where amount and rate are used. Here are just a few:

Amount Rate How much money: [dollars] Rate of earning money: [dollars/hour of income] Distance traveled: [meters] Rate of traveling: [meters/second or speed] How much energy: [joules] Rate of gaining energy: [watts (J/s) or power]

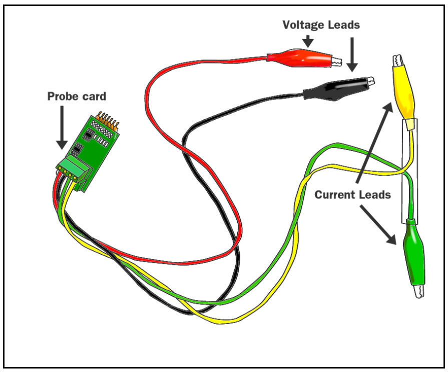
In all of these cases to display the rate of change, the amount is graphed against time and results with the slope of that graph being the rate. If the rate is plotted against time, the area under the graph will be the amount that is accumulated.

The mini light shows that electrical energy can also be turned into light energy. The process is indirect, however. Light is a byproduct of heating the little wire in the bulb to a white-hot temperature. The wire radiates light and other invisible radiation in all directions. The clear tape lets most but not all of it through, but the aluminum foil blocks the light from radiating. Therefore the Temperature probe heats faster when the light is surrounded by foil. The energy is transformed from electrical to heat to light and back to heat again.

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.

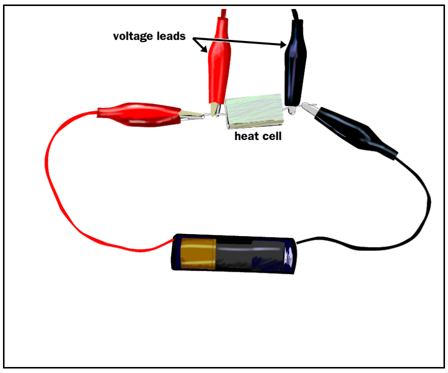


The only sensitive part is the tip where two special bare wires are twisted together. The wires produce a voltage depending on the temperature, and the CCProbe software converts this to degrees (C or F). The response is very fast, because the two wires are small and easily heated or cooled by whatever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



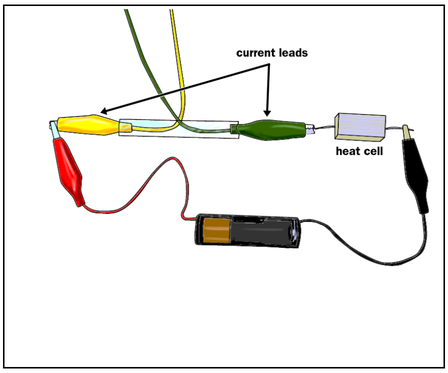
The Voltage/Current Probe measures either voltage or current. It can also measure both at the same time. The CCProbe software can use these readings to calculate and display power (watts) and energy (joules).

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.



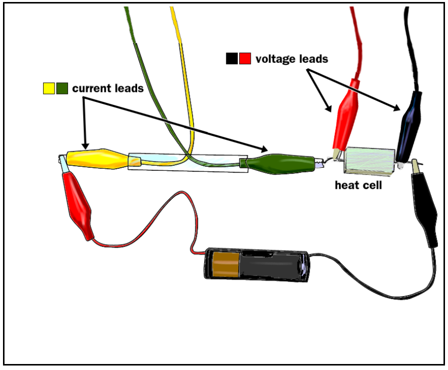
Current is the amount of electricity flowing, a bit like the current in a stream. Current can be pictured as the total number of electrons flowing per second through a wire or other substance. You can imagine measuring current by setting up a tollbooth in a wire and simply counting how many electrons 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: Cranking with a Genecon

One class period - Trial II: Heating with a battery

One class period - Trial III: Heating with a light bulb

One class period - Analysis and "Wrap Up" discussion

Additional days can be used for Further Investigations.

