PocketLab Voyager: Investigating Thermoelectric Generators

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Introduction

A ***t****hermo****e****lectric* ***g****enerator (****TEG***) is a device that converts temperature differences directly into electrical energy. This is different than a heat engine, which converts temperature differences into mechanical energy. TEGs are commonly made using bismuth telluride (Bi_2Te_3) semiconductor thermocouples with n- and p-doping and alloyed using antimony or selenium. The doping introduces impurities purposely to alter the electrical properties of the semiconductors. The thermocouples are connected in series using copper bridges, and the copper bridges are bonded together thermally by ceramic plates, typically using aluminum oxide (Al_2O_3) as shown in Figure 1.

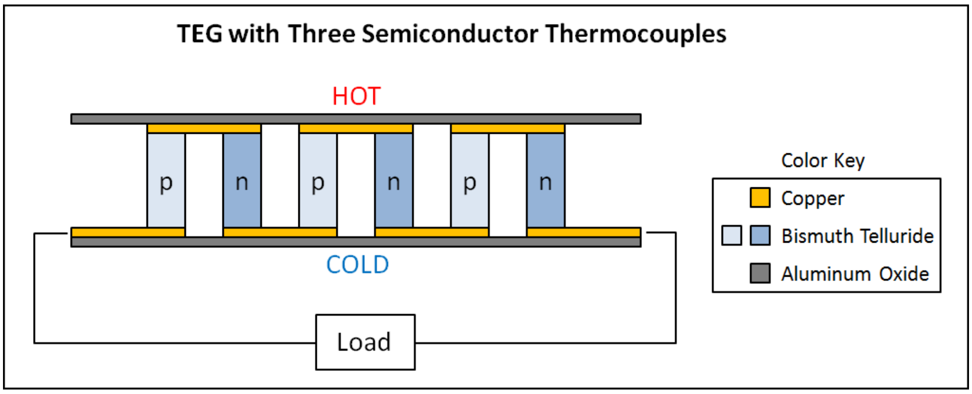

Figure 1

Figure 2 shows a typical TEG that is 40 mm x 40 mm x 3.5 mm. A Universal specification identification has been established for thermoelectric devices. An example specification is ***TEC1-12706***. ***TE*** stands for **T**hermo-**E**lectric. ***C*** refers to standard size, while ***S*** would refer to small size. The ***1*** after TEC tells the number of stages. The number ***127*** tells us that there are 127 P-N couples in the module. The final two digits, ***06*** in this case, indicate the maximum current rating.

There are a number of properties of thermoelectric generators that are advantageous in many applications:

- Having no moving parts, they require little maintenance and run silent and vibration-free.
- Their small size, flexible shape, and orientation insensitivity make them ideal for small applications.
- They can be used in severe environments.
- They have a long life, with large mean-time-between-failure (MTBF), and are easy to replace when they do fail.

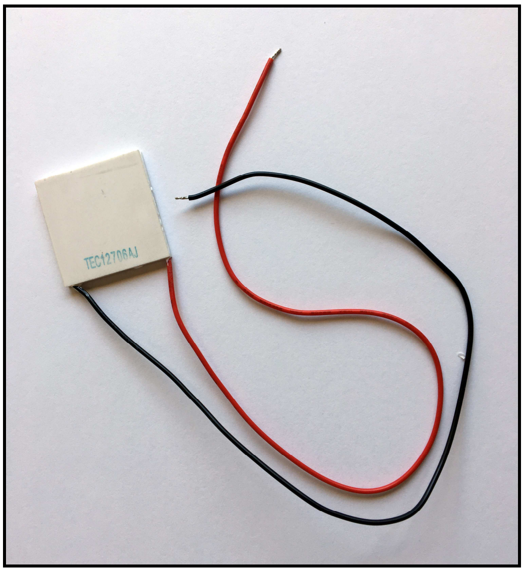

Figure 2

In the past several years, there has been a great deal of research in the use of TEGs to recover electrical energy from waste heat produced in a variety of systems: waste heat recovery in exhaust gases from automobile internal combustion engines, power sources for wireless sensor networks, electric power generation from wood-burning stoves, heat from radioactive isotopes providing electrical power for space probes, megawatt power recovery from hot gases produced by internal-combustion power plants, and production of electric power from body heat to power wrist watches. With all of these and many other uses, the study of thermoelectric generators in physics and engineering curricula is well worth including in NGSS-based coursework.

Our Thermoelectric Generator Experiment

In the early 1800's, the physicist Thomas Seebeck discovered a phenomenon that would later be referred to as the ***Seebeck effect***—the ability to convert a temperature difference (ΔT) into a voltage difference (ΔV) when two different metals are interfaced. It has been found that the direction of heat flow determines the voltage polarity and the magnitude of the voltage difference ΔV is proportional to the temperature difference ΔT. The purpose of our experiment is to verify this proportionality between ΔV and ΔT.

A TEG is sandwiched using thermal grease, available at many hardware and building supply stores, between two containers, one with very hot water (red), and another with ice cold water (blue), as shown in Figure 3. ***The tight bond provided by the thermal paste if critical for success in this experiment****.* Any container with ***flat vertical sides*** will do, but it is best to use containers that are small in order to keep the time for data collection to about one-half hour. The containers shown in Figure 3 hold about 75 ml each, and a pack of four was obtained for about $3.50 from a Wal-Mart store's office products department. Several napkins are placed below the containers to help prevent conductive heat losses/gains by container contact with the surface of the table. The sides of the containers must be flat and vertical so that the TEG can be tightly fixed to both containers. The TEG can be purchased from a variety of places online with prices widely varying from a dollar to prices on the order of $20. For example, at adafruit.com, the price of a TEC1-12706 (search there for "thermo-electric") was $11.95 as of September 21, 2017.

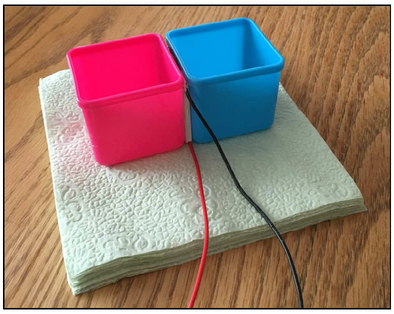

Figure 3

Experiment Setup

See Figure 4 contains a bird's eye view of the experiment setup. Two PocketLab Voyagers, with plug-in external temperature probes attached, are used for collecting temperature data at a rate of 1 point per second. Black electrical tape is used to attach the probes to the inside of each container on the sides of the containers sandwiching the TEG. To provide the temperature difference, hot water is in the red container, while cold water is in the blue container. The initial temperatures were close to the freezing point of water and the boiling point of water. ***Students must use caution in working with the hot water to avoid scalding***. A digital multimeter is connected to the wires on the TEG in order to collect open circuit voltage data while the cold container warms up and the hot container cools down over time. The multimeter must be capable of reading voltage in the millivolt range. Readings of the multimeter are taken and recorded once every minute. Data was collected over a period of about 25 minutes.

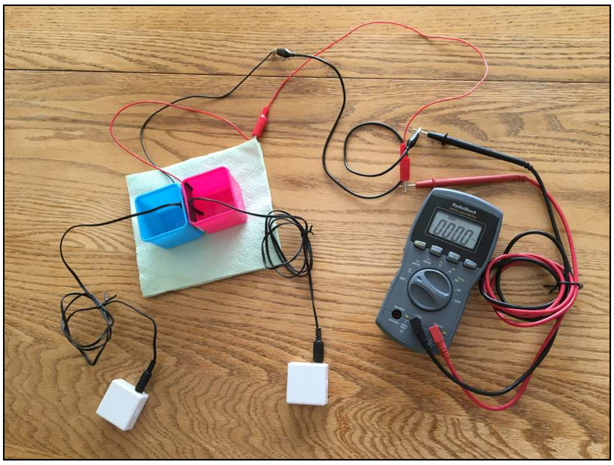

Figure 4

Results

Figure 5 shows a chart of the temperature of the hot container, the cold container, and the *temperature difference* between the two containers over a time period of 1500 seconds (25 minutes). This chart was constructed in Excel from data collected by the PocketLab app csv files. As discussed earlier, it is the ***temperature difference*** that is of interest in the Seebeck effect. We need a graph of voltage vs. temperature difference to determine the relationship between these two variables.

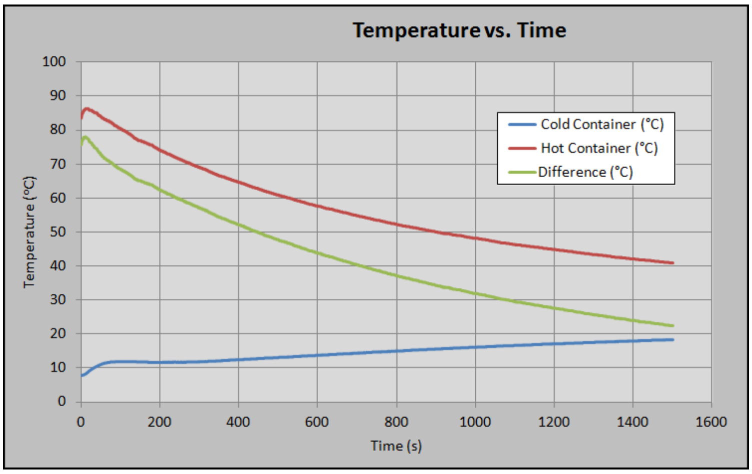

Figure 5

The left side of Figure 6 shows that the open circuit voltage is decreasing as time progresses. The right side of Figure 6, however, is the result that we have been hoping to see. The open circuit voltage appears to be proportional to the temperature difference, as a linear fit to the data points shows an R^2 value very close to 1. We see that the open circuit voltage increases at a rate of 0.0078 mV per °C temperature difference for our TEG module.

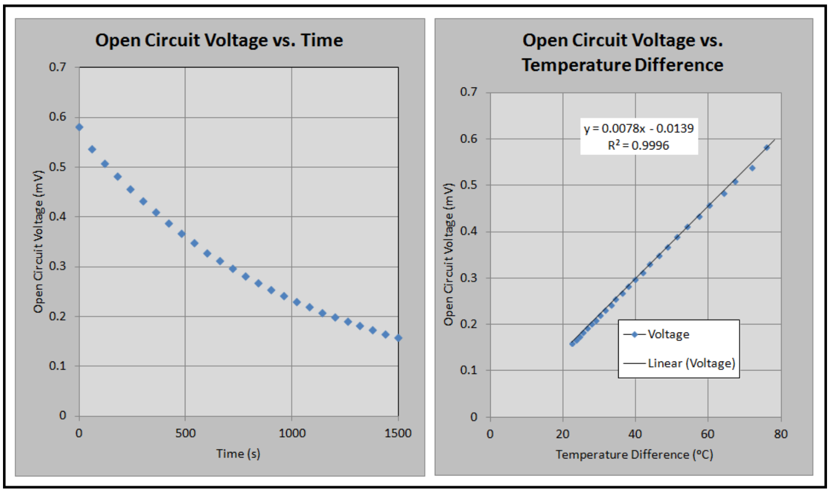

Figure 6