PocketLab Voyager: Investigating Thermoelectric Cooling

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Introduction

Vapor-compression refrigeration, providing cooling for our home refrigerators and air conditioners as well as large frozen foods warehouses, is familiar to almost everyone. Such systems are commonly studied in thermodynamics physics courses. Another type of cooling, having its roots back in the early 1800's, is ***thermoelectric cooling***. A French watchmaker and physicist, Jean Charles A. Peltier, observed that electric currents produce heating or cooling at the interface between two dissimilar metals. This is now known as the Peltier effect and is used in numerous cooling applications, including air cooling of small refrigerators, beverage cooling in camping, cooling of electronic components, extraction of water in air by dehumidifiers, and cooling of CCDs in telescopes, spectrometers and cameras.

Peltier coolers are now 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. Essentially, a Peltier cooler is a solid-state heat pump that transfers heat from one side of the device to the other side while consuming electrical energy.

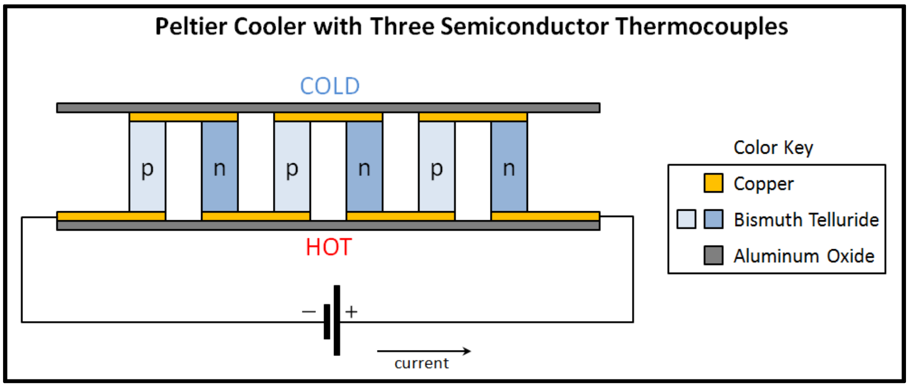

Figure 1

Advantages and Disadvantages

Peltier coolers have a significant number of advantages over traditional vapor-compression refrigeration. Since Peltier coolers have no moving parts, they require less maintenance and run silent and vibration-free. Since they have no circulating liquids and associated leaks, they are not ozone depleting, and therefore do not contribute to the greenhouse effect. Their small size, flexible shape, and orientation insensitivity make them ideal for small applications. They can also be used in severe environments that would not be possible with traditional refrigeration. They have a long life, with large mean-time-between-failure (MTBF), and are easy to replace when they do fail. With feedback circuitry controlling the voltage and current, they can be used in applications requiring temperature control to within small fractions of a degree.

The primary disadvantage of Peltier cooling is that it is lower in efficiency than standard vapor-compression refrigeration. As a result, it is most useful in applications where the solid state advantages noted above outweigh efficiency considerations. The hot and cold sides of a Peltier cooler are quite close together—typically from 3 to 5 mm apart, as shown in Figure 2. This results in the need for large heat sinks and fans to carry heat away from the modules.

The heat sink and fan keep the hot side at ambient temperature, and without them, the hot side would get so hot that the entire device would fuse together.

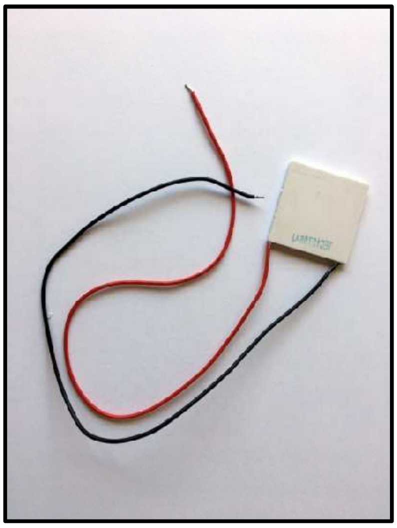

Figure 2

While it is possible to purchase the individual components (Peltier module, heat sink, fan, etc.) and then construct the complete apparatus yourself, it is also possible to purchase a completely assembled Peltier assembly at a very reasonable price. (For example, at adafruit.com, a 12V5A *Peltier Thermo-Electric Cooler Module + Heatsink Assembly* costs $34.95. A compatible *12V5A switching power supply* costs $24.95. A *Female DC Power Adapter—2.1 mm jack to screw terminal block* to connect the power supply to the Peltier module costs $2.00. Total cost $61.90.) Figure 3 shows the **adafruit** apparatus used in this investigation. The entire assembly is small—roughly 9 cm square by 7.5 cm high.

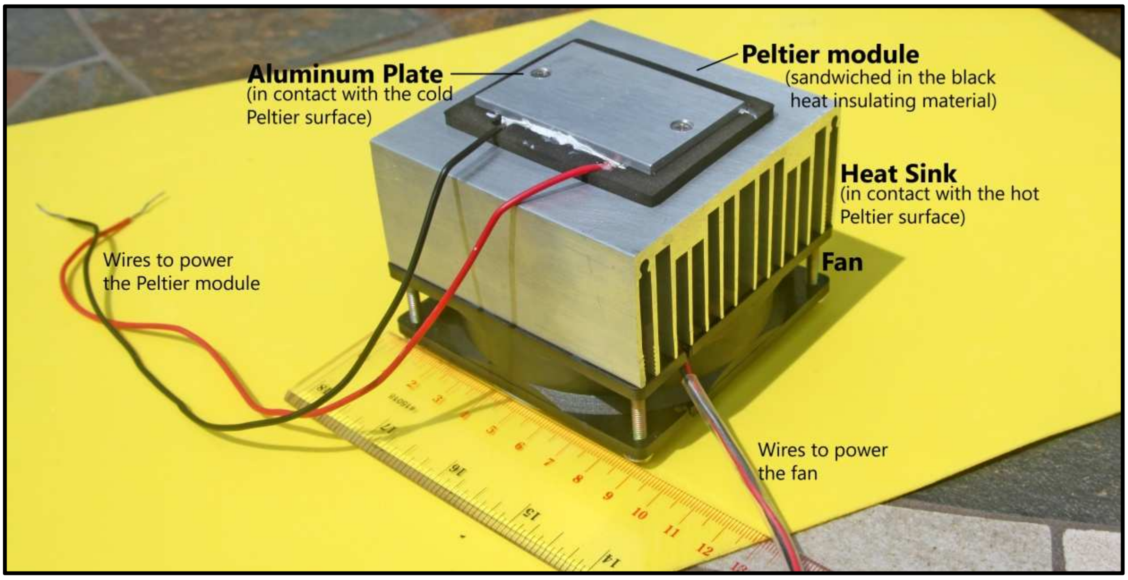

Figure 3

Universal specification identification has been established for thermoelectric Peltier 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. (Multistage Peltier modules can provide greater cooling power.) 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. Therefore, you do need to use a 12V power supply that will provide a current of at least 5A, but not more than 6A.

Experiment Setup

Figure 4 shows the setup for the thermoelectric cooler investigation. Two PocketLab Voyagers, with the plug-in external temperature probes attached are used to collect data. One of temperature probes is taped to the cold side of the thermoelectric module using black electrical tape. The other probe is inserted into the inside top of the heat sink to give an indication of the rise in temperature of the hot side of the thermoelectric module. Both the fan and the thermoelectric module are connected to the 12V5A power supply (not shown in the figure). The Voyager external temperature probes are ideal for this experiment due to their rapid response to temperature changes.

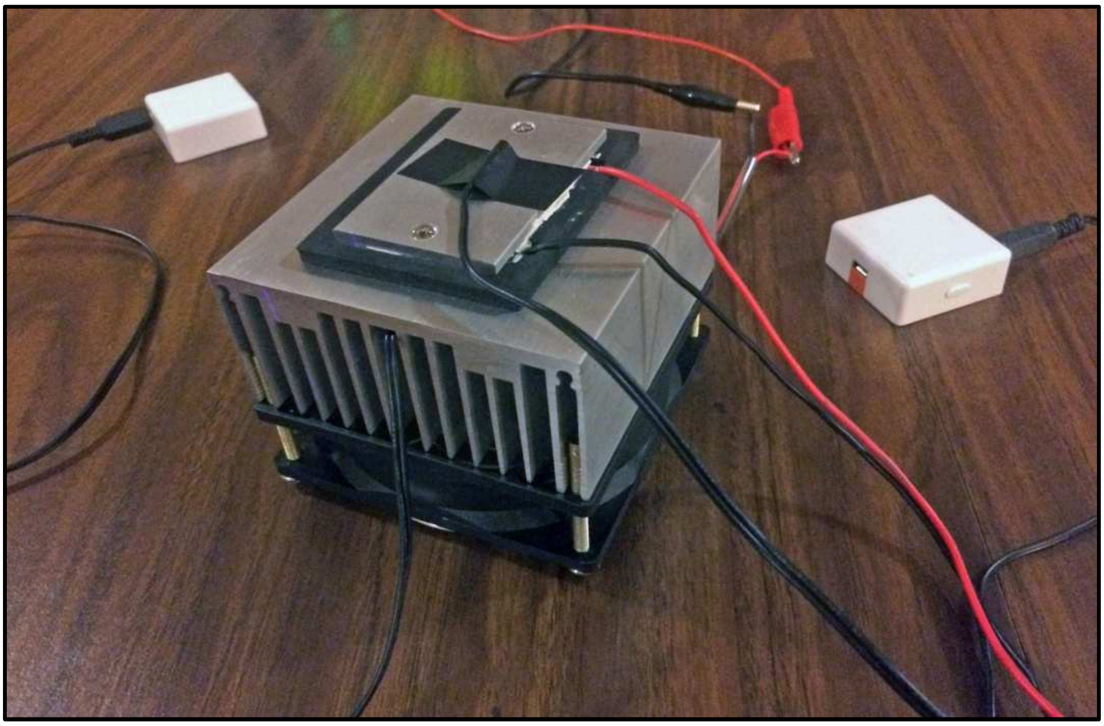

Figure 4

***Cautions**: It is very important that the fan be running to carry away heat produced by the hot side of the thermoelectric module, otherwise the entire module will melt and fuse together. It should also be noted that the hot side may get hot enough to cause skin burns, so it should not be touched. Finally, the cold side will likely get to the freezing temperature of water or lower in less than a minute. So you should avoid extended contact to keep from getting frostbite.*

Results

Figure 5 shows an Excel chart constructed from temperature data collected by the csv files produced by the PocketLab app. Data was collected for somewhat less than 3 minutes with a data collection rate of 1 point per second.

We first note that at time 0, the temperature of both probes was about 21ºC, the temperature of the room. The red line on the graph shows a gradual rise in the temperature of the heat sink as it collects heat from the hot side of the thermoelectric module. The temperature would have risen much higher (and faster!) if the fan had not been turned on to carry away the excess heat. The fan is indeed critical.

The blue line on the graph shows a rapid decrease in the temperature of the cold side of the thermoelectric module. The cold side reached the freezing point within less than 90 seconds and evened out at a temperature of about -3ºC within 3 minutes. It should be noted that a small insulating piece of packing material, not shown in Figure 4, was placed over the top of the cold side to insulate it from the ambient temperature of the room, much like how a refrigerator keeps cold.

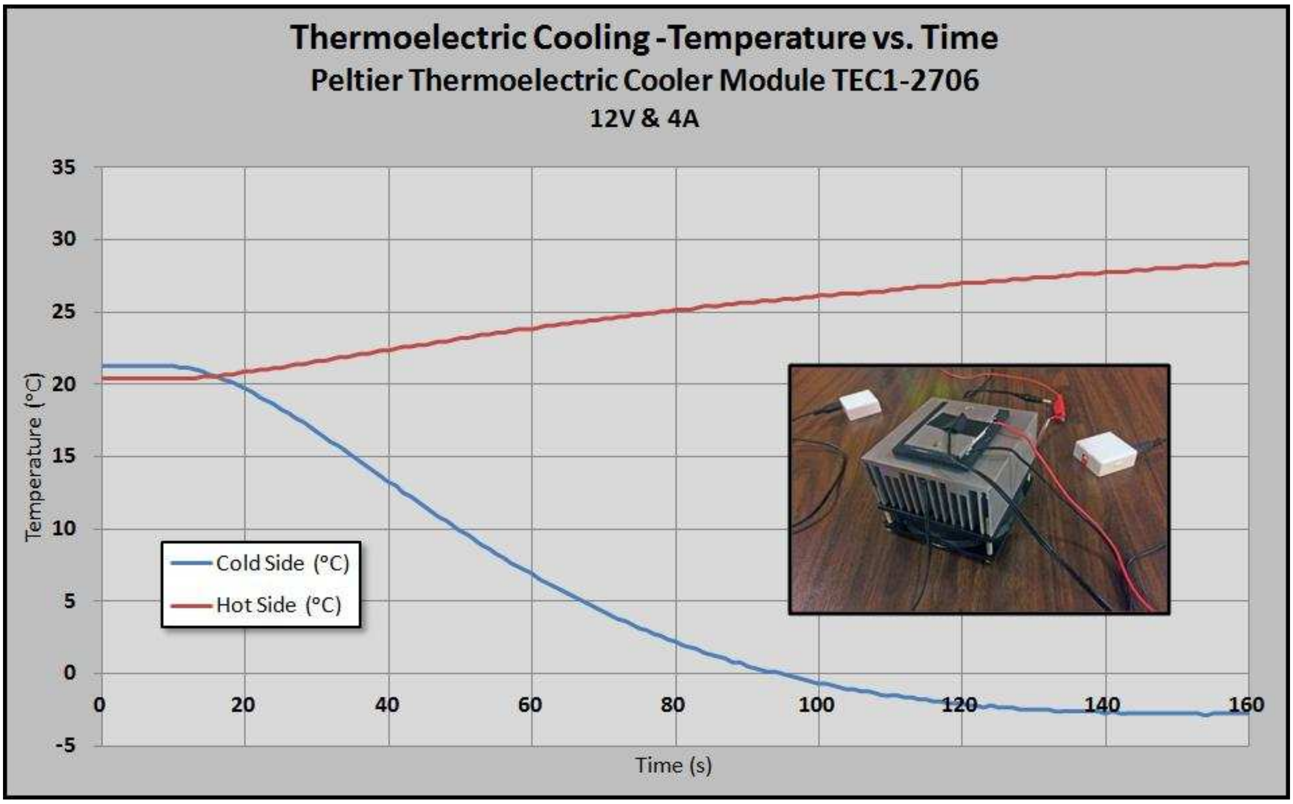
Thermoelectric Cooling -Temperature vs. Time
Peltier Thermoelectric Cooler Module TEC1-2706
12V & 4A
Temperature (°C)
Time (s)
Cold Side (°C)
Hot Side (°C)
35
30
25
20
15
10
5
0
-5
0
20
40
60
80
100
120
140
160

Figure 5