## HOA 1 – Evaluating the use of Peltier modules for practical applications

This HoA is worth a total of 4% of the total marks allocated for Physical World. This activity is based on: (1) answers to the group worksheet, graded out of 25 points and (2) an individual quiz, graded out of 20 points, in Week 9 Cohort 1 or 2. If you did not attend the lab session or have poor lab conduct, you will lose all 25 points assigned to this HoA. Submit one worksheet per group.

### Introduction

The use of thermoelectric (TE) devices to convert heat flow directly into electrical power via the Seebeck effect has been a subject of interest[3]. Peltier module is a solid-state device which transfers heat from one side of the device to the other. It is constructed of two ceramic plates with p and n semiconductors in between. When heat is provided and allowed to flow spontaneously from one side of the Peltier module to the other side, electric current will be generated (Seebeck effect). This setup is known as Thermoelectric generator (TEG)[3]. The newer generation of thermoelectric material has a predicted device conversion efficiency of 15%–20%[4]. Research in thermoelectric has been focused on increasing the Figure of merit (ZT) of thermoelectric material to improve the efficiency[5] which is currently way below efficiency achievable by conventional power plants. In order to use TE devices as a TEG with the current materials, it will only be sensible if a waste heat source is used[6] .

Alternatively, electric current can be supplied to TE device to pump heat non-spontaneously from cold to hot to produce a Thermoelectric cooler (TEC) [3]. This process is known as Peltier effect.

### Intended Learning Outcome

- Student should be able to perform analysis using the fundamental laws of thermodynamics, electrical circuits' laws (i.e., Ohm's law, Kirchhoff's Laws) and engineering principles
- Students should be able to model TE devices and predict the theoretical efficiency
- Student should be able to evaluate the efficiency of a thermoelectric device and perform optimization

### Experimental Procedure

You will be given

(1) power supply
(2) breadboard,
(3) data logger
(4) Peltier module that has two aluminum blocks fastened to each side of the Peltier that are in good thermal contact with the ceramic plates (Figure 1). The aluminum blocks function as the Hot and Cold Reservoirs.

A python program will be used to record the temperatures of the aluminum blocks, voltage and current flowing through.

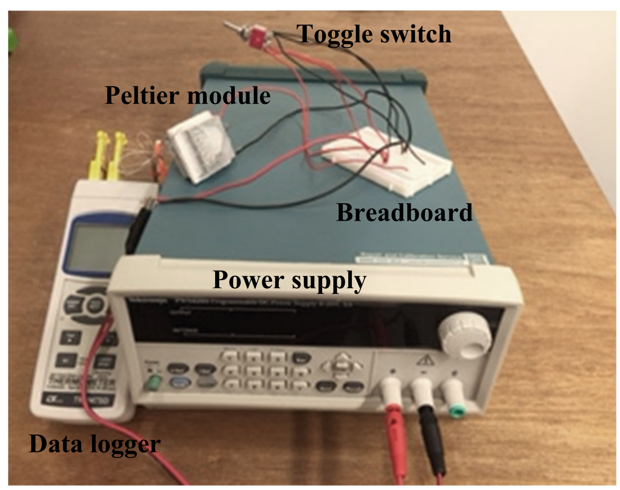
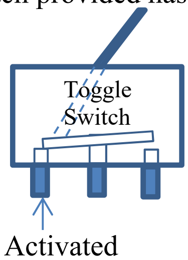



Figure 1

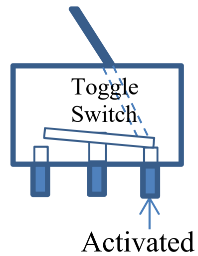
**Part 1: Peltier effect – Heat pump mode (non-spontaneous heat flow)**

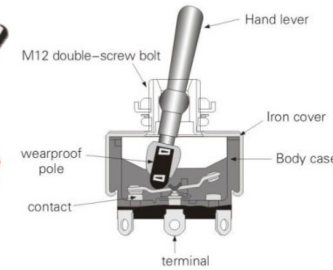
(1) The toggle switch provided has 2 positions.

(2)




Position 1 completes the circuit to the power supply - provides the power to the Peltier to pump heat from one aluminum block to the other (Thermoelectric cooler (TEC)).




Position 2 completes the circuit to allow electrical power produced by the Peltier module through heat flow from the hot aluminum plate to the cold aluminum plate (Thermoelectric generator (TEG)) to flow to a load resistor. Power is no longer drawn from the power supply.

(3) Connect the toggle switch, Peltier and the two given wires to the breadboard and power supply such that when the toggle switch is in position 1, the power supply is supplying electrical power to pump heat from one side of the Peltier module to the other (TEC) (Figure 2a). When the toggle switch is in position 2, the setup will allow the heat from the hot end of the Peltier module to move spontaneous to the cold end to generate an electric current (TEG) (Figure 2b) and the power supply will act as a voltmeter.

(4)

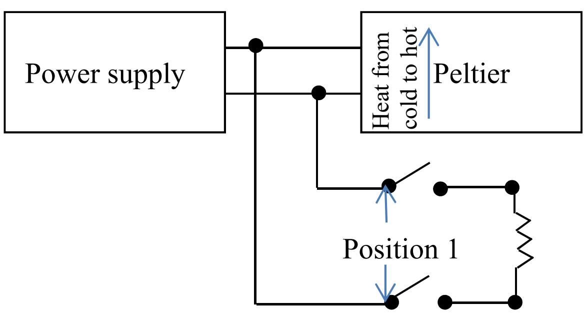



Figure 2a: Peltier Module as TEC

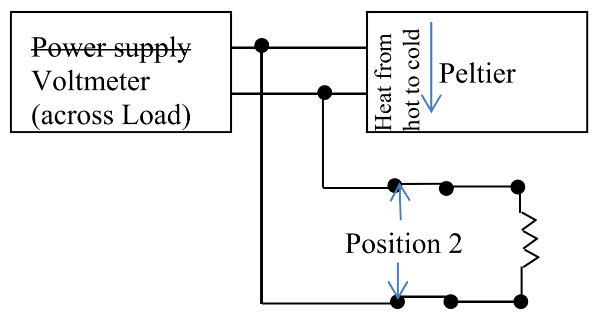



Figure 2b: Peltier Module as TEG

(5) Ensure that when the toggle switch is at Position 1

a. there is a complete circuit from the power supply to the Peltier
b. the computer is connected to the data output port (RS232) on data logger and power supply for data recording
c. the thermocouple is connected to the thermometer, and the thermometer is turned on.

(6) Turn on the power supply.

(7) When ready, launch ‘exp1win’. The program should have been loaded on your computer. One of the aluminum blocks will feel cold to the touch after some time.

(8) The program will run for about 1 min. The data will be saved and transferred to your “notepad”. Please ensure that the data are stored properly.

**Caution: Do not touch the hot aluminum block when it is running in this mode. Keep the temperature of the hot aluminum below 80 °C to prolong the life of the Peltier. Do not allow the Peltier to exceed a temperature of 130°C. It will melt the solder!**

**Part 2: Seebeck effect – Heat engine mode (spontaneous heat flow)**

The power generated by the Peltier is correlated to the output load resistance. In this section of the activity, you will observe the output power as you vary the load resistors while keeping the temperature differential as constant as possible between load resistors.

(1) Exit “exp1win”

(2) Ensure the aluminum blocks are at room temperature before the start of each experiment.

(3) Connect a load resistor to Position 2 on the breadboard.

(4) Launch “exp2win”

(5) The program will allow the Peltier to pump heat from the cold reservoir to the hot reservoir for about a minute. A temperature gradient between the two blocks will be established.

(6) Pay attention to the screen. A prompt **“Flip the toggle switch”** will appear after 60 seconds. Flip the toggle switch to position 2.

(7) Once the switch is flipped to position 2, the power supply will no longer supply power to the Peltier. Heat will flow from the hot aluminum block, through the Peltier, into the cold block. Part of this heat that flows out of the hot aluminum block will be converted to electrical energy to supply the load resister.

(8) The ‘exp2win’ program will stop automatically once the potential difference reaches 0.001V. The data will be saved and transferred as “notepad’.

(9) Exit “exp2win”

(10) Repeat Step 3 to 8 with all five of the load resistors. Before each experiment, allow the block to cool down to around room temperature.

**Note:** For Part 2, the fourth column during the first 60 seconds of the recorded data reads the current flowing from the power supply. After 60 seconds, the data in the fourth column is the potential built-up across the resistor due to the temperature difference on the two aluminum heat reservoirs.

**References:**

1. Power Generation from Coal: Measuring and Reporting Efficiency Performance and $CO_2$ Emissions, International Energy agency https://www.iea.org/ciab/papers/power_generation_from_coal.pdf
2. U. Buskies, “The efficiency of coal-fired combined-cycle powerplants,” Appl. Therm. Eng. **16**, 959–974 (1996).
3. Thermoelectric Power Generator Design and Selection from TE Cooling Module Specifications, Richard J. Buist and Paul G. Lau, TE Technology, Inc., 1590 Keane Drive, Traverse City, MI 49686 USA Phone: (616) 929-3966, FAX: (616) 929-4163, E-mail: cool@tetech.com
4. Y.Z. Pei, X.Y. Shi, A. LaLonde, H. Wang, L.D. Chen, G.J.Snyder Convergence of electronic bands for high performance bulk thermoelectrics Nature, 473 (2011) 66-69
5. E Bell, Lon Cooling, Heating, Generating Power, and Recovering Waste Heat with Thermoelectric Systems Science, 321 (2008) 1457-61
6. http://fortune.com/2015/06/24/heat-power-tech-cars/

Information for this activity is modified from Pasco manual for energy transfer thermoelectric manual.

**Analysis**

**Part 1: Peltier effect – Heat pump mode (non-spontaneous heat transfer)**

The Peltier is doing work to pump heat from the cold aluminum to the hot aluminum (Figure 3). The work done by the Peltier can be represented as

$W$ = area under input power curve

$P$ = Input power = Voltage × Current

$\dot{Q}_h$ = heat pumped into the hot aluminum

$\dot{Q}_c$ = heat pumped out of the cold aluminum

The heat transfer rate is related to temperature change by

$$\dot{Q} = mc\frac{dT}{dt}$$

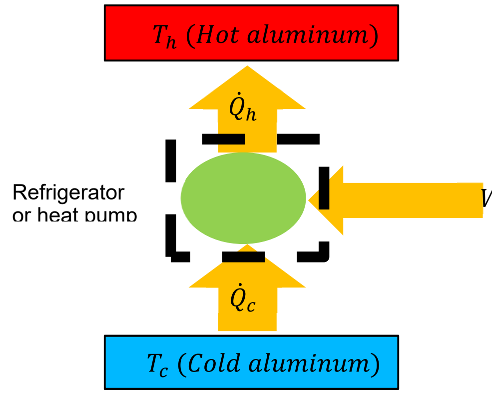



Figure 3

$\dot{Q}$ = heat transfer

$m$ = mass of the aluminum block

$c$ = specific heat of aluminum

$\frac{dT}{dt}$ = change in temperature with time

** $\frac{dT}{dt}$ may be treated as an average that does not change with time or as a time dependent variable. You should model $\frac{dT}{dt}$ as a time dependent variable in this activity.

**Part 2: Seebeck effect – Heat engine mode (spontaneous heat transfer)**

As heat transfers spontaneously from the hot aluminum block to the cold aluminum block, the Peltier converts this heat transfer into work, and some of this heat transfers into the cold aluminum (see Figure 4).

$\dot{W}$ = work done by the heat engine

$\dot{Q}_h$= heat transfer out of the hot aluminum

$\dot{Q}_c$= heat transfer into the cold aluminum

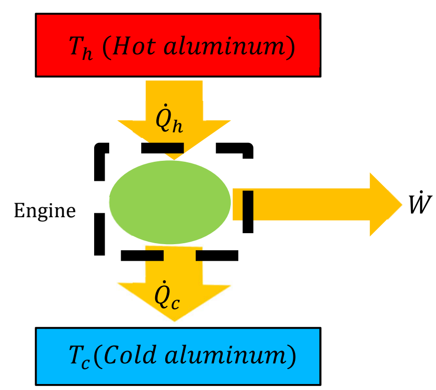



Figure 4

First Law of Thermodynamics: $\dot{Q}_h = \dot{W} + \dot{Q}_c$

**Dimensions of one aluminum block = 3 cm × 3 cm × 1 cm**

**Density of aluminum block = 2.7 g/cm$^3$**

**Specific heat capacity of aluminum block = 0. 9 J/(g. °C)**