Experiment 2:
Load Resistance and Efficiency

Equipment Required	Part Number
Thermoelectric circuit board	part of ET-8782
Foam insulators (qty. 2)	part of ET-8782
Heat sink and thumbscrew	part of ET-8782
Banana patch cords (qty. 6)	part of ET-8782
Temperature cables (qty. 2)	part of ET-8782
DC Power Supply (10 V, 1 A minimum)	SE-9720A or equivalent
PASPORT Voltage/Current Sensor	PS-2115
PASPORT Quad Temperature Sensor	PS-2143
PASPORT interface(s)	PS-2001 or equivalent
DataStudio software	See PASCO catalog
“Load Efficiency” configuration file for DataStudio	part of ET-8782

Introduction

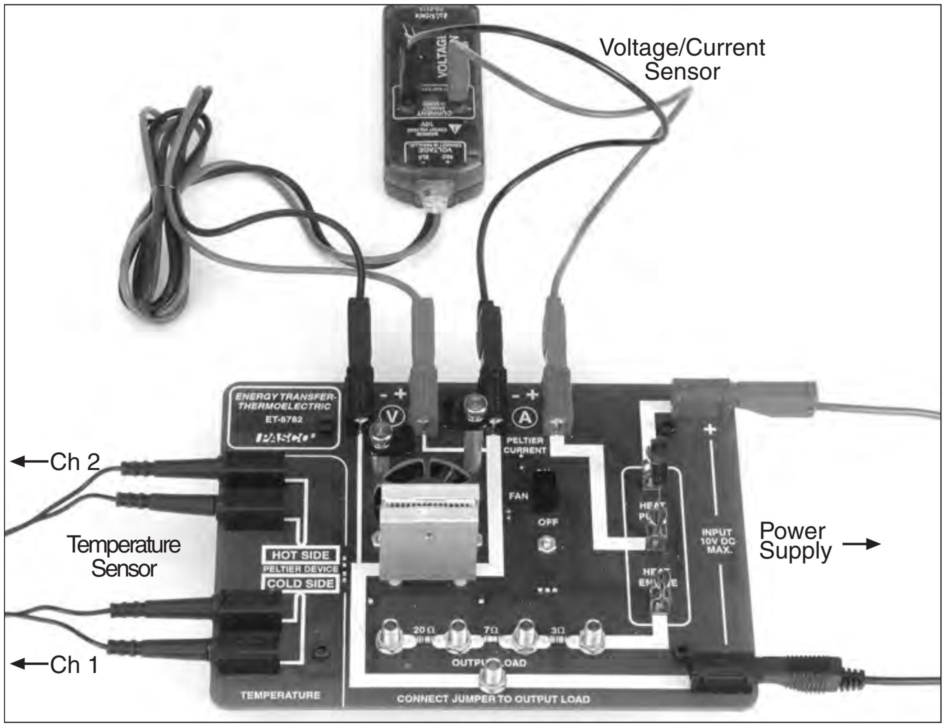
In this experiment you will examine the relationship between output load resistance and the power generated by the peltier when it is operating in heat engine mode.

You will observe the output power as you vary the load resistance while keeping everything else constant (the temperature difference between the blocks, for instance). Since it is not possible to hold the blocks at a steady temperature difference, you will take the peltier through several identical cycles of heating and cooling, and measure the power each time a certain temperature difference occurs. You will repeat the cycle for each value of load resistance that you test, ranging from slightly over 0 Ω to 30 Ω.

Before you start, predict what you will discover about the relationship between output power and load resistance. Record your prediction using words, numbers and a graph. Explain your reasoning.

Set-Up

1. *Input Power:* Set the Heat Pump/Heat Engine switch to the neutral position (straight up). Connect the power supply using banana patch cords to the input power terminals on the circuit board as shown in picture. Note the polarity.

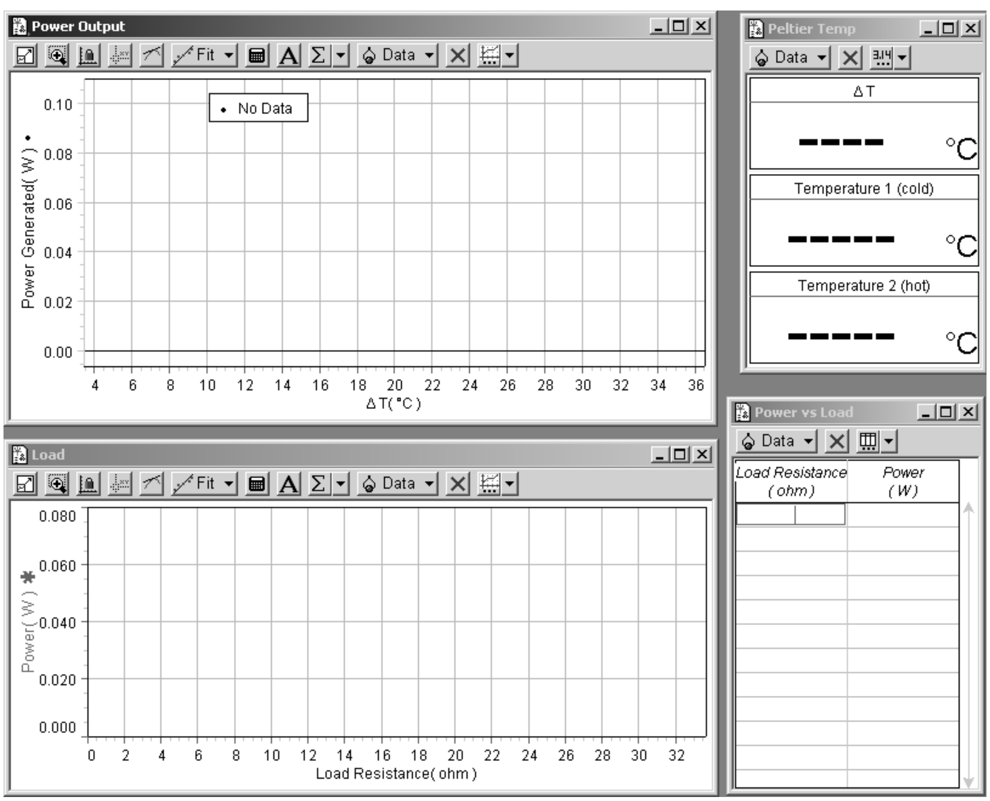


2. *Temperature:* Connect the cables from the temperature ports to the Quad Temperature Sensor. Connect the Cold Side to Channel 1 of the sensor and the Hot Side to Channel 2.

3. *Voltage:* Connect the voltage leads of the Voltage/ Current Sensor to the Voltage Ports on the board. Note the polarity.

4. *Current:* Connect separate red and black banana patch cords from the current input of the Voltage/Current sensor to the Current Ports on the board. Note the polarity.

5. *Computer:* Connect the sensors to the computer through the PASPORT interface. Open the pre-configured DataStudio file "Load Efficiency". The display should look as shown below.



Background

This section explains some of the details of the DataStudio configuration file.

Calculations: DataStudio will measure the temperature of both blocks (T_{hot} and T_{cold}), the voltage across the load resistor, and the current through the load resistor. From these measurements it will make two calculations, temperature difference (ΔT) and output power (P), using the following equations:

$$\Delta T = T_{\text{hot}} - T_{\text{cold}}$$

$$P = \text{current} \times \text{voltage}$$

Start and Stop Conditions: DataStudio has been configured with start and stop conditions, which control when it records data. The *start condition* is that ΔT must drop below 35 °C. Before the beginning of each cycle (when $\Delta T < 35\ ^\circ\text{C}$) you will click the Start button; DataStudio will display live data, but it will not start recording. Data recording will not start until the ΔT has increased above 35 °C and then dropped back below that level. The start condition will enable you to view the temperature measurements without recording them. The *stop condition* will cause data recording to stop when ΔT drops below 5 °C.

Changing the Name of a Data Run: DataStudio will record a separate data run for each load resistance. In order to keep track of them, you will rename each data run. By default, the runs are named Run #1, Run #2, *etc*. In order to rename a run, find it in the Summary window (on the left side of the screen), click on it once to select it, then click on it again to edit it (be careful to single-click twice, and not to double-click). Enter the new name (for instance, “7 ohms”). When DataStudio asks if you would like to rename all the data from this run, select Yes.

Procedure

1. Click the Start button. DataStudio will show live temperature readings in the Digits display, but it won’t start recording yet.

2. Observe the temperature of both sides of the peltier; both should be close to room temperature. During the experiment, you will take the peltier through several cycles of heating and cooling. You must ensure that both sides of the peltier are close to room temperature before each cycle starts. Note the room temperature for future reference.

3. Set the voltage on power supply to about 6 volts. Set the switch to Heat Pump mode for about 2 seconds, then return it to the neutral position. If the voltage/current sensor beeps, then the current is too high (over 1 amp) and you should decrease the voltage (then close the switch again to test it).

4. Set the switch to the Heat Engine position and allow the blocks to cool. Wait until both sides are within a few degrees of room temperature. (To cool faster, install the heat sink on the hot block and turn on the cooling fan. It also helps to put a metal object in contact with both blocks.)

5. Connect the output load jumper to terminal D. This bypasses all of the resistors and reduces the load resistance to almost zero. Note that the resistance is not exactly zero because the wires and traces on the board have some resistance.

6. Place both insulators on the blocks.

7. Set the switch to Heat Pump mode. Watch the difference in temperature between the two blocks (ΔT). You are waiting for ΔT to reach 35 °C, which will take about one minute.

8. When ΔT reaches 35 °C, change the switch to Heat Engine Mode. The temperature difference will start to decrease. When ΔT drops below 35 °C, DataStudio will automatically start recording. You will see data appear on the graph of Power Generated vs. ΔT.

9. When ΔT drops below 5 °C, data recording will stop automatically.

10. Change the name of the data run to indicate the load resistance.

11. Click Start. DataStudio will display temperature data, but it won't start recording yet.

12. Remove the insulators and use the fan and heat sink to cool the blocks to within a few degrees of room temperature.

13. Change the output load to 3 Ω (connect the jumper to terminal C).

14. Replace the insulators and repeat the cycle of heating and cooling. (Go back to step 7.)

15. Repeat the cycle again for the following values of output load:

- 7 Ω (Connect the jumper to B, but also connect a shorting jumper from C to D.)
- 10 Ω (Connect the jumper to B.)
- 20 Ω (Connect the jumper to A, but also connect a shorting jumper from B to D.)
- 30 Ω (Connect the jumper to A.)

When you are finished, you will have acquired power and temperature data for six different values of output load resistance.

Analysis

From the data that has been recorded you will extract the data needed to plot a graph of Power Generated (P) versus Load Resistance (R_L) at ΔT = 30 °C.

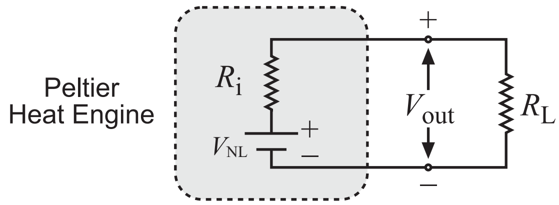
On the graph of P vs. ΔT use the smart cursor to read the power generated at ΔT = 30 °C for each value of load resistance. (Use the zoom select tool to change the scale of the graph and enlarge the area around the data at 30 °C in order to read the data precisely.)

Enter the values in the Power vs. Load table. As you enter data into the table, they will be plotted on the Power vs. Load Resistance graph.

1) At what value of R_L is the maximum power generated?

2) For output loads less than *and* greater than the optimal value, why does the peltier generate less power?

All real electrical power supplies (including the peltier heat engine) have an internal resistance, R_i. They can be modeled as an ideal voltage source in series with a resistor, as shown below (with an output load connected).



The voltage of the ideal voltage source, V_{NL}, is called the no-load voltage. For a peltier heat engine V_{NL} depends only on ΔT.

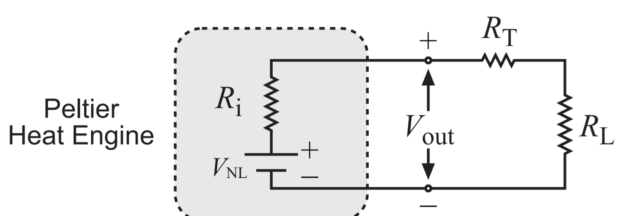
3) Under what condition does the output voltage (V_{out}) equal V_{NL}?

4) How would you directly measure V_{NL} at ΔT = 30 °C?

5) Write a theoretical equation for output power, P, in terms of V_{NL}, R_i and R_L. Make a graph of P vs. R_L (choose some arbitrary values for V_{NL} and R_i). Based on your equation and graphs, under what condition is P at its maximum?

6) In this experiment, one of the data points was taken with $R_L = 0$. According to your equation, what is the theoretical power generated when $R_L = 0$? Was this the case in your experiment?

There is another source of resistance that we haven't considered yet, which is the resistance of the traces, leads and sensors in the circuit. Let's call it R_T. If we add in R_T, the circuit can be modeled thus:



7) Rewrite the theoretical equation for P taking R_T into account.

8) Fit this equation to your experimental data. What is the no-load voltage at ΔT = 30 °C? What is the internal resistance of the peltier? What is R_T?

Further Investigation

1. Make a direct measurement of the no-load voltage at ΔT = 30 °C.

2. Make a direct measurement of R_T (or measure as much of it as possible).

3. Predict how your results would differ if you repeated your analysis for a different value of ΔT? Test your prediction.
4. For your graph of Power vs. Load Resistance, what did you do to ensure that only R_L and P varied, and that all other experimental parameters stayed constant? Evaluate how successful these measures were. Discuss how you could improve them.
5. In the analysis we assumed that V_{out} was constant for all values of ΔT = 30 °C. Do an experiment to test that assumption.
6. For any given output load, quantitatively describe the relationship between P and ΔT.