Experiment 1: Conservation of Energy and the First Law of Thermodynamics[1]

Introduction

In this activity you will study the flow of energy in the experimental set-up as you run it through a cycle.

First you will operate the apparatus in Heat Pump mode, in which energy is supplied to the Peltier, and the Peltier pumps heat from one aluminum block to the other. After a temperature difference has been established between the blocks, you will switch the Peltier into Heat Engine mode, in which heat flows from the hot block, through the Peltier, and into the cold block. The Peltier will convert some of the heat that flows out of the hot block to electrical energy, which it will supply to the load resistor.

During this cycle you will follow the energy as in moves in different forms from the power supply to the peltier (electrical energy), in and out of the aluminum blocks (heat or thermal energy), and into the load resistor (electrical energy). As you do the experiment, bear in mind the law of conservation of energy and the first law of thermodynamics. How do they relate to the transfer of energy within the system?

Set-Up:

The blade switch allows you to switch between powering the heat pump and sending the power produced by the heat engine to a load. For both halves of the cycle you will collect data using the Capstone software produced by Pasco. In particular, you will need to monitor the electrical power and the temperature of each plate.

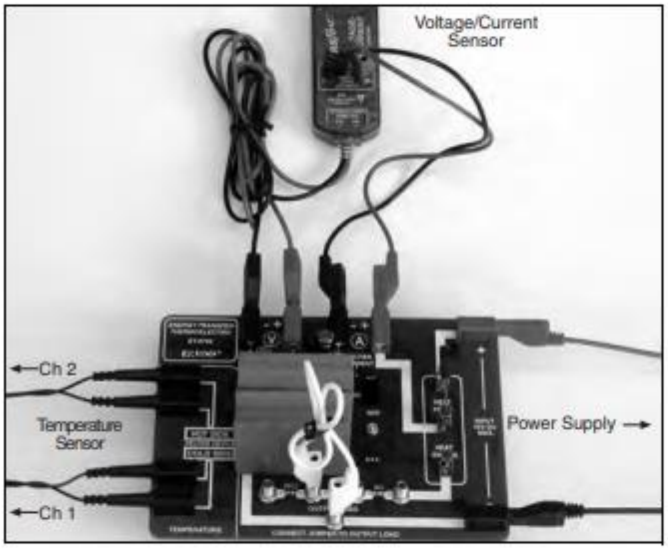

Figure 1 The Peltier refrigerator with recommended connections for power, load, and monitoring equipment.

The heat pump

You will power the heat pump with a DC power supply (use 3-4V), wire it up and then add appropriate connections to monitor voltage across the Peltier and

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[1] An adaptation of the instructions provided by Pasco with the Peltier Refrigerator lab apparatus.

current through it using the Passport Voltage/Current Sensor.

Connect the on-board thermometers to the Passport Quad Temperature Sensor.

The heat engine

In addition to the connects above give a path to ground for the 10Ω (=3Ω +7Ω) load.

When using the apparatus as a heat engine be sure to insulate both blocks from the air in the room.

Background

You will measure and record the temperature of both aluminum blocks, the voltage and current applied to the Peltier during Heat Pump mode, and the voltage and current generated by the peltier during Heat Engine mode. From these measured quantities, you will use the capstone software to calculate and display heat flow, power and work. The following sections explain how to make those calculations.

Heat vs. Temperature

You will calculate the heat (Q_{hot} or Q_{cold}) that flows into or out of the aluminum block on either the hot or cold side of the Peltier based on temperature change. The relationship between heat flow and temperature change is given by

$$Q = m\,c\,\Delta T$$

where:

Q = heat transferred,

m = mass of the aluminum block,

c = specific heat of aluminum = 0.90 J/(g·°C),

ΔT = change in temperature.

A positive value of Q may represent heat transferred into or out of the aluminum block, depending on whether the block is on the hot side or the cold side of the Peltier, and whether the Peltier is operating as a heat pump or a heat engine.

The temperature of each block is measured via the embedded thermistor. The mass of each block is about 19 g. You should find a more precise value for the mass by measuring the block's volume with calipers and use the density of aluminum, 2.7 g/cm^3, to calculate the mass.

Input Power and Work Done by the Peltier Heat Pump

In Heat Pump mode, Input Power from the power supply equals the rate at which the Peltier does work to pump heat out of the cold reservoir and into the hot reservoir. The Voltage/Current Sensor measures the voltage applied to the peltier, and the current that flows through it. The electrical power in is:

$$Power = Voltage \times Current.$$

Energy is the integral of the power

$$E = \int P\,dt$$

which is also the area under the power vs time plot. For Energy Input use Input Power versus time.

Power Generated and work done by the Peltier Heat Engine

In Heat Engine mode, Power Generated is the rate at which the Peltier does work on the load resistor. The Voltage/Current sensor measures the voltage across the resistor and the current through it. From these measurements, calculate the power supplied to the load resistor. The area under the plot of Power Generated versus time equals the work that the Peltier has done on the resistor.

Procedure

Before you start, the aluminum blocks should both be at room temperature. The knife switch should be in neutral position (straight up) and the fan should be switched off.

Set the DC Voltage to between 3 and 4 volts.

Start data recording, then set the knife switch to Heat Pump. You will see Input Power data appear in the top section of graph. The area under the graph equals the energy supplied to the Peltier, which equals the work done by the heat pump. You will determine the heat pumped out of cold reservoir (Q_{cold}) and the heat deposited into the hot reservoir (Q_{hot})

Observe how the temperatures of the aluminum blocks change.

Run the peltier in Heat Pump mode for about a minute (or until the cold side appears to reach a minimum temperature), then switch to Heat Engine mode.

Again, observe how the temperatures of the aluminum blocks change.

Power Generated data now appears in the bottom section of the graph display. The area under the graph equals the energy generated by the heat engine and supplied to the load resistor. You will determine the heat that has flowed out of the hot reservoir (Q_{hot}) and the heat that has flowed into the cold reservoir (Q_{cold}). Continue to record until the aluminum blocks are close to the same temperature.

Analysis

Heat Pump Mode

In Heat Pump mode the Peltier does work to pump heat out of the cold reservoir and into the hot reservoir.

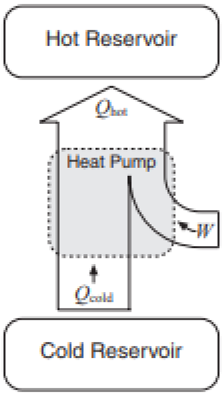

Figure 2 Peltier device used as a heat pump.

W = work done by the Peltier (equal to the area under the Input Power curve),

Q_{hot} = heat pumped into the hot reservoir,

Q_{cold} = heat pumped out of the cold reservoir.

By the first law of thermodynamics,

$$Q_{hot} = Q_{cold} + W$$

1. Where did the heat pumped out of the cold reservoir go? Where did the heat pumped into the hot reservoir come from? Why was more heat pumped into the hot reservoir than was pumped out of the cold reservoir?
2. Compare your observed values of (Q_{cold} + W) and Q_{hot}. If they are not equal, where did the "lost energy" go?
3. Write an equation in terms of the "lost energy", E_{lost}, and your observed data, W, Q_{hot} and Q_{cold}.

Heat Engine Mode

In a heat engine, heat flows out of the hot reservoir, some of the heat is converted to work, and the rest of the heat flows into the cold reservoir.

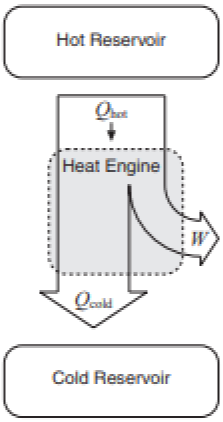

Figure 3 Peltier device used as a heat engine.

W = work done by the heat engine,

Q_{hot} = heat flow out of the hot reservoir,

Q_{cold} = heat flow into the cold reservoir.

By the first law of thermodynamics,

$$W = Q_{hot} - Q_{cold}$$

4. Compare your observed value of work, $W_{observed}$ (which is the area under the Power vs. Time plot) to the quantity $Q_{hot} – Q_{cold}$. Are they equal?
5. In a real heat engine, only part of the heat that flows out of the two-reservoir system ($Q_{hot} – Q_{cold}$) is converted to useful work. In this experiment, the work that you observed (the useful work) was the work done on the load resistor. Can you account for all of the energy that flowed out of the hot reservoir with your values of $W_{observed}$, Q_{hot} and Q_{cold}? If not, where did the "lost energy" go?
6. Calculate the proportion of net heat flow from the aluminum blocks that was converted to useful work;

7. Write an equation in terms of the "lost energy", E_{lost}, and your observed data, $W_{observed}$, Q_{hot} and Q_{cold}.
8. In this experiment the "useful work" was the work done on the load resistor. What was the result of doing work on the resistor? How could you modify the circuit in order to make better use of the work done by the heat engine? Conservation of Energy In the Heat Pump phase of the cycle the power supply put energy into the system. Then, in the Heat Engine phase heat flowed out of the hot reservoir and part of it was converted into electrical energy, which was supplied to the load resistor.
9. Calculate the percentage of energy put in during the Heat Pump phase that was recovered as useful work during the Heat Engine phase;
10. Is this a good way to store energy?

Conduction and Heat Flow Through the Insulators

One of the losses of energy in this experiment has to do with heat flow by conduction through the polyethylene foam insulators. The rate of heat flow through the insulator is

$$\frac{Q_i}{t} = kA\frac{\Delta T}{x}$$

where:

Q_i/t = heat flow rate through the insulator,

k = thermal conductivity of the polyethylene foam = 0.036 W/(m·°C),

A = area through which the heat flows,

ΔT = temperature difference across the insulator,

x = thickness of the insulating material.

You will estimate the amount of heat that flowed through the foam in contact with the front face of the cold block.

Measure the height and width of the cavity in the insulator that surrounds the aluminum block. Calculate the cross-sectional area, A in m^2.

Measure the thickness, x, of the foam that covers the front face of the block. Do not include the sides of the foam (you are only calculating the heat flow through the front face). Record your measurement in meters.

From the temperature graph, determine the difference, ΔT, between the temperature of the cold block and room temperature. This value changed during the experiment, so record the maximum difference, when the cold block was at its coldest. This will give you an estimate of the maximum heat flow rate through the insulator.

11. Calculate the heat flow rate through the foam, Q_i/t. This is the heat flow rate in joules/second. To find the total amount of heat in joules, multiply this number by the total time in seconds that the experiment ran; Q_i = (heat flow rate) × (time).
12. How does your estimate of Q_i compare to the heat, Q_{cold}, that was pumped out of the cold block in the Heat Pump phase? Is it much larger, much smaller, or similar?
13. Is your estimate of heat flow through the insulator too high or too low? Remember that you ignored the sides in your estimate, and that you used the maximum temperature difference for ΔT.
14. How would the flow of heat through the insulator on the hot side compare to heat flow through the insulator on the cold side? Consider both the magnitude and direction of heat flow.
15. Is heat flow through the insulators (on the hot and cold sides) a significant factor in this experiment? Could the heat flow through the insulators account for the discrepancy between your observed results and the first law of thermodynamics?
16. How would your results have differed if you had not used the insulators? Further Investigation What are some factors that you could vary in the experimental apparatus and procedure? Predict how changing those factors would affect the results. Do an experiment to test one of your predictions

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What are some factors that you could vary in the experimental apparatus and procedure? Predict how changing those factors would affect the results. Do an experiment to test one of your predictions.