**Instruction Sheet
for the PASCO
Model TD-8550A**

THERMOELECTRIC CONVERTER

Introduction

The PASCO scientific Thermoelectric Converter consists of a thermoelectric heat pump sandwiched between two aluminum metal legs. Electric current from the thermoelectric heat pump can drive a small motor that has a fan attached to its shaft. The Converter can demonstrate the Seebeck effect (discovered in 1821). In this effect, a temperature difference across the thermoelectric heat pump gives rise to a current that drives the small motor ($\Delta T \rightarrow E$). For example, when one leg is in hot water and the other is in cold water, the small motor turns the fan. The Converter can also demonstrate the Peltier effect (discovered in 1834). When a current is passed through the thermoelectric heat pump, a temperature difference results ($E \rightarrow \Delta T$). One of the legs becomes warm while the other leg becomes cooler. Finally, the Converter acts as a "thermal capacitor". After a current is passed through the Converter to create the temperature difference ($E \rightarrow \Delta T$), flip the switch ($\Delta T \rightarrow E$), and the temperature difference causes a current that drives the small motor.
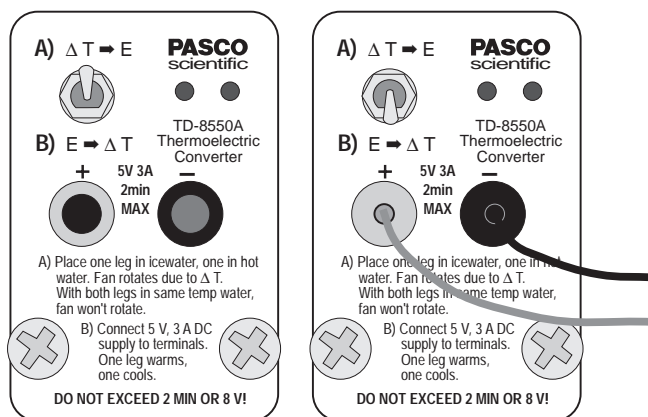

Figure 1 Switch Position

Figure 1 shows the top portion of the Thermoelectric Converter. Put the switch in the "up" position (toward

$\Delta T \rightarrow E$) in order to demonstrate the Seebeck effect (temperature difference causes electric current). Connect a source of electric current to the red and black banana jacks and put the switch in the "down" position (toward
$E \rightarrow \Delta T$) to demonstrate the Peltier effect (current through the thermoelectric heat pump causes a temperature difference).

> ◗ **NOTE:** The recommended voltage and current is 5 Volts and 3 Amps (DC). ***Do not exceed 8 Volts.*** Do not run the 5 Volt, 3 Amp current through the device for more than ***2 minutes***.

Equipment Needed:

- Cups for hot and cold water
- DC Power supply capable of 5 Volts and 3 Amps
- Patch cords

Recommended Equipment:

- TD-8556 Steam Generator
- SF-9584 AC/DC Low Voltage Power Supply or SF-9582 12 Volt AC/DC Power Supply
- SE-9750 and SE-9751 Banana Plug Patch Cords

Optional Equipment:

- Digital thermometer (such as PASCO Model SB-9631 or Model SE-9086)

Theory

A transformation whose only final result is to transform into work heat extracted from a source which is at the same temperature throughout is impossible.

Lord Kelvin

PASCO ®
scientific

10101 Foothills Blvd. • Roseville, CA 95747-7100
Phone (916) 786-3800 • FAX (916) 786-8905 • www.pasco.com

better
ways to
teach science

This was Kelvin's statement of the Second Law of Thermodynamics. The second law has been stated in many, seemingly unrelated ways; but in the end, all have been shown to be different ways of expressing the same basic principle. In its most general form, the Second Law tells us that no physical process will occur if it decreases the disorder—or *entropy*—of the universe. Conservation of energy, as expressed in the First Law of Thermodynamics, holds for every physical process. But many processes which would conserve energy do not occur. The Second Law describes this phenomenon.

OPERATION

Seebeck Effect:

The PASCO Model TD-8550A Thermoelectric Converter is designed to demonstrate this relationship between the First and Second Laws of Thermodynamics. The procedure used directly illustrates Kelvin's statement of the Second Law. The Converter is used as illustrated in Figure 2. Put the switch in the "up" position. One leg of the unit is placed in a cup of cold water and one in a cup of hot water. (Boiling water and ice water give good results.) Some of the thermal energy from the hot water is converted into work by the Converter, and the fan turns. Then the hot and cold water are mixed together in a larger container. Both legs of the unit are placed into the container. Now the fan does not turn.

The total internal energy of the water is not changed by mixing the hot and cold together, so there must still be sufficient energy in the water to turn the fan. But this would violate the Second Law of Thermodynamics, as stated by Kelvin.

> ➡ **NOTE:** As a further demonstration, place one leg in the mixed water (or in ice water) and one in a container of dry ice to demonstrate that there is energy available in the mixed water (and even in ice water).

This violation of the Second Law can also be explained in terms of entropy, using the expression $\Delta S = Q/T$, where ΔS is the change in entropy, Q is the heat transferred, and T is the temperature at which the heat is transferred. Considering only the heat transfer taking place in the cups of water, the following holds:
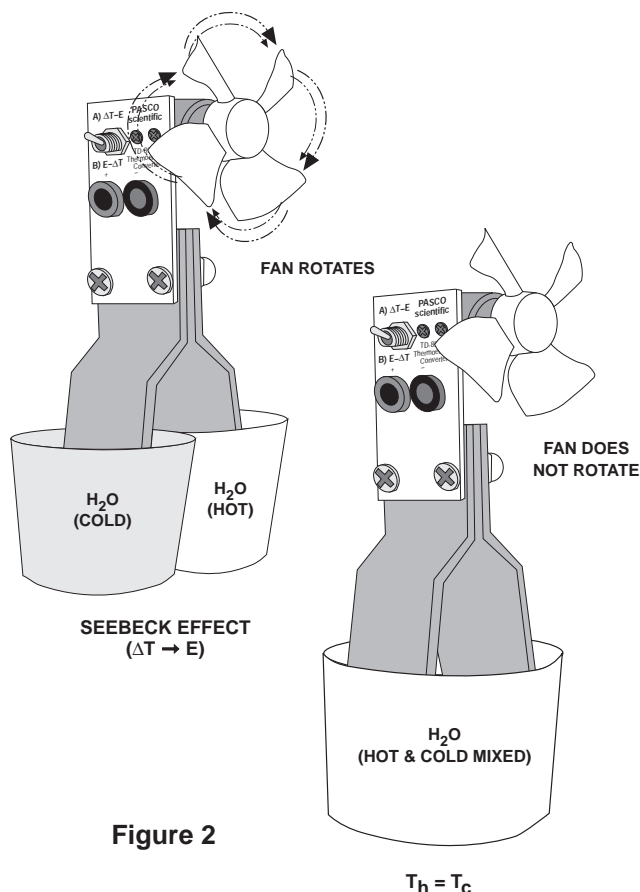

FAN ROTATES

FAN DOES NOT ROTATE

H₂O (COLD)

H₂O (HOT)

SEEBECK EFFECT ($\Delta T \to E$)
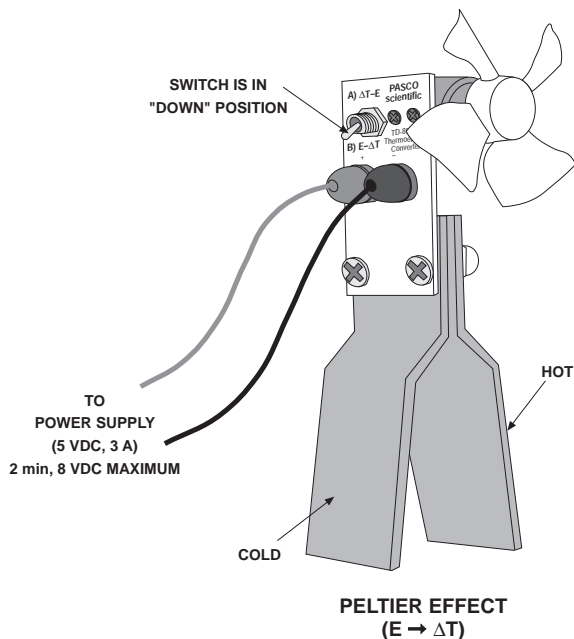
H₂O (HOT & COLD MIXED)

Figure 2

$T_h = T_c$

① The change in entropy of the hot water, $\Delta S_h = Q_h/T_h$, is negative, because of the heat transfer from the water into the Converter.

② The change in entropy of the cold water, $\Delta S_c = Q_c/T_c$, is positive, because of the heat transfer from the Converter into the water.

③ According to the second law, the total change in entropy, $\Delta S_T = \Delta S_c + \Delta S_h$, must be positive. Therefore, the process will only take place if $Q_c/T_c > Q_h/T_h$.

④ In order for the fan to be turned, some of the heat transferred from the hot water must be converted into work and will therefore not be available to be transferred back into the cold water. Therefore, whenever the fan turns, $Q_h > Q_c$.

⑤ The equations in steps 3 and 4 can only both be true if $T_h > T_c$. Once the water is mixed, however, $T_h = T_c$. Therefore, if the fan were to turn, it would violate the Second Law of Thermodynamics.

PASCO scientific

Peltier Effect:

During the Peltier effect, a current through the thermo-electric heat pump of the Converter causes a temperature difference. Connect a DC power supply capable of 5 Volts and 3 Amps to the red and black terminals on the Converter. Put the switch on the Converter to the E → ΔT (down) position . (*For this demonstration, you do not need to immerse the legs of the Converter in water.*) Turn on the power supply. In a few moments you should be able to feel the temperature difference of both aluminum legs of the Converter.

> ▶ **NOTE:** DO NOT LEAVE THE POWER SUPPLY ON FOR MORE THAN TWO MINUTES. DO NOT EXCEED 8 VOLTS.

As an optional exercise, begin with the Converter at room temperature. Measure the temperature of both legs. Then, while the current is applied to the Converter, use a digital thermometer to monitor the increase in temperature of the "hot" leg and the decrease in temperature of the "cold" leg.

PELTIER EFFECT
(E → ΔT)

SWITCH IS IN "DOWN" POSITION

TO POWER SUPPLY (5 VDC, 3 A) 2 min, 8 VDC MAXIMUM

HOT

COLD

Thermal Capacitor:

After demonstrating the Peltier effect, disconnect the power supply from the Converter. Put the switch to the ΔT → E (up) position. The temperature difference caused when the current was applied to the thermoelectric heat pump will now cause the Converter to generate a current to drive the motor.

FAN ROTATES
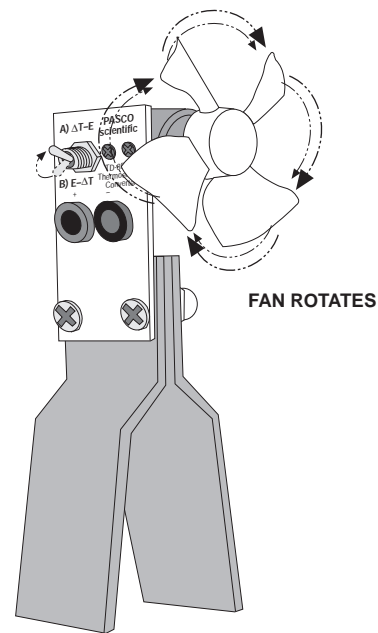
"THERMAL CAPACITOR"
(MODIFIED SEEBECK EFFECT)

Description of Seebeck effect

The Thermoelectric Converter uses a series of thermo-electric cells to convert thermal energy into electrical energy that will drive the fan. Each cell is a semiconductor device. A simplified diagram of one cell is shown below.
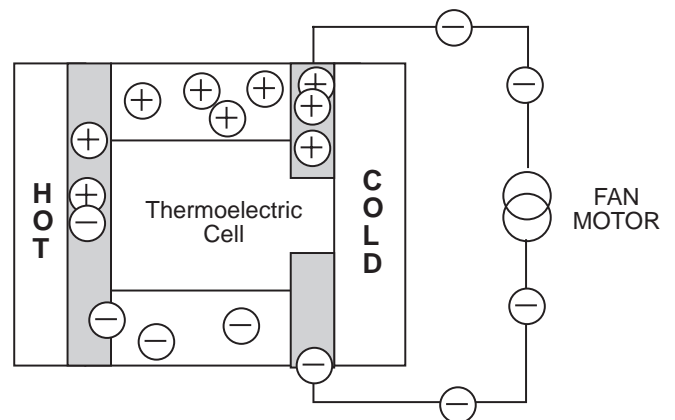
Thermoelectric Converter Cell (Seebeck effect)

HOT   COLD   Thermoelectric Cell   FAN MOTOR

During the Seebeck effect, the heat entering the cell raises the energy level of some of the electrons in the cell. At the higher energy level, the electrons are no longer bound in the crystal structure of the semiconductor and are free to move. When they do so, they leave a vacant place, or hole, in the crystal. Lower energy electrons, though they can't move freely within the material, can jump from hole to hole. In this way, the holes can also migrate through the semiconductor material.

3

PASCO scientific

The electrons migrate, as shown, through the N-type semiconductor material and the holes migrate through the P-type material. (N and P type materials are merely silicon that is "doped" with special impurities that enhance electron and hole migration.) The electrons flow through the external circuit and drive the fan motor. At the other end of the circuit they reenter the cell and encounter the holes of the P-type semiconductor. This occurs near the cold end of the cell. The electrons can therefore drop back into holes, giving up any excess energy they still retain as heat.

As long as the temperature differential is maintained between the two sides of the cell, the electrons and holes continue to migrate, and the fan continues to turn. However, if there is no temperature differential, the electrons can not recombine with the holes because there is no place to give up their excess energy. In this way, the thermoelectric cell is constrained by the Second Law of Thermodynamics.

Description of Peltier effect

During the Peltier effect, the electric potential difference causes electrons and holes to migrate from one end of the N and P type semiconductor material to the other. The movement of the electrons in the N type semiconductor results in a transfer of internal energy from that end of the semiconductor, and it cools. The same result occurs for the P type semiconductor during hole migration. The heat transfer from the "cold" leg to the "hot" leg is proportional to the carrier current passing through the circuit and the number of thermoelectric cells (couples) making up the thermoelectric pump.
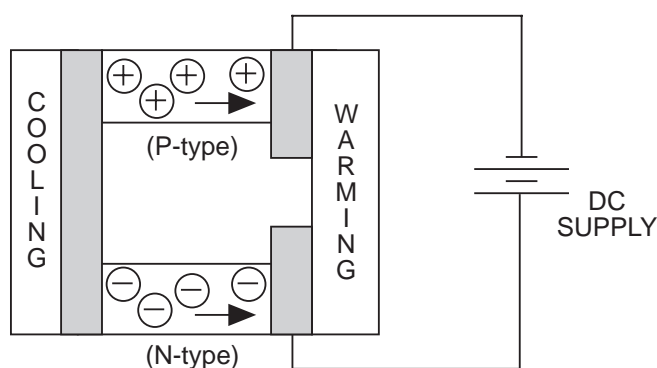
Thermoelectric Converter Cell (Peltier effect)

Construction of the Thermoelectric Heat Pump:

The PASCO Thermoelectric Converter has 71 thermoelectric cooling "couples". These are made from two elements of semiconductor, primarily Bismuth Telluride (a quarternary alloy of bismuth, tellurium, selenium and antimony) heavily doped to create either an excess (N-type) or deficiency (P-type) of electrons. The couples, connected in series electrically and in parallel thermally, are integrated into the thermoelectric heat pump. The heat pump is packaged between metallized ceramic plates.

Specifications:

When using the Thermoelectric Converter as a Peltier device, the power required to produce a given temperature difference depends on the temperature of the hot side. The hot side must never exceed 135 degrees C, the melting point of the solder which bonds the Bismuth Telluride ingots to the plates. Starting at 25 degrees C, the hot leg temperature increases much more than the cold leg temperature decreases (about 40 degrees versus about 8 degrees in 2 minutes). This is because the power dissipated by the hot side is the sum of the supplied power and the heat transferred from the cold side. (If the hot side is held to 25 degrees C, enough power can be applied to create a maximum temperature difference of about 67 degrees C.)

The resistance of the small motor is about 1 ohm.

Compatible PASCO Equipment

PASCO offers a complete line of laboratory and demonstration equipment for thermodynamics. Experiment quantitatively with the mechanical and electrical equivalents of heat, thermal conductivity, heat capacity, phase changes in water, and black body radiation.

Check our catalog for these and other products that can bring PASCO quality into your classroom and laboratory.

Limited Warranty

PASCO scientific warrants this product to be free from defects in materials and workmanship for a period of one year from the date of shipment to the customer. PASCO will repair or replace, at its option, any part of the product which is deemed to be defective in material or workmanship. This warranty does not cover damage to the product caused by abuse or improper use. Determination of whether a product failure is the result of a manufacturing defect or improper use by the customer shall be made solely by PASCO scientific. Responsibility for the return of equipment for warranty repair belongs to the customer. Equipment must be properly packed to prevent damage and shipped postage or freight prepaid. (Damage caused by improper packing of the equipment for return shipment will not be covered by the warranty.) Shipping costs for returning the equipment, after repair, will be paid by PASCO scientific.

PASCO scientific