7-2019

Energy Transformation and Conservation Investigation

Mike Jackson

Holly Haney

Grade: 11-12 Chemistry	**Topic: Energy Transformation and Conservation**	**Lesson # 2 (90 minutes) of 2**

Brief Lesson Description:
Students will use a thermoelectric generator module to analyze the relationship between thermal and electrical energies. Using data collection sensors and analysis software, students will investigate the relationship between the temperature gradient across a thermoelectric generator module and the resulting electrical potential. Students will then use their data and analysis to solve problems relating to waste thermal energy in electrical systems and communicate their work to their peers and teacher.

Before proceeding with this lesson, the teacher should familiarize him / herself with Vernier Logger Pro®:

***Vernier Logger Pro®* Overview:** https://www.vernier.com/products/software/lp/

Performance Expectations/Standards:
Students who demonstrate understanding can:

P3-ETS1-2. **Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.** [AR Clarification Statement: Examples could include designing and building a machine, using schematics to break down an engine into major functional blocks, and designing improvements to reduce total energy loss from a home.]

P3-ETS1-3 **Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics, as well as possible social, cultural, and environmental impacts.** [AR Clarification Statement: Examples could include evaluating the different parts of a machine, the entire machine, and reducing energy loss in homes.]

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Planning and Carrying Out Investigations ● Plan and conduct an investigation individually and collaboratively to produce data to serve as the basis for evidence, and in the design: decide on types, how much, and accuracy of data needed to produce reliable measurements and consider limitations on the precision of the data (e.g., number of trials, cost, risk, time), and refine the design accordingly. (P-PS2-5, P-PS5-1AR) **Obtaining, Evaluating, and Communicating Information** Obtaining, evaluating, and communicating information in 9–12 builds on K–8 experiences and progresses to evaluating the validity and reliability of the claims, methods, and designs. ▪ Communicate scientific ideas (e.g. about phenomena and/or the process of development and the design and performance of a proposed process or system) in multiple formats (including orally, graphically, textually, and mathematically). (P-PS5-3AR)	**PS3.A: Definitions of Energy** ▪ Energy is a quantitative property of a system that depends on the motion and interactions of matter and radiation within that system. That there is a single quantity called energy is due to the fact that a system's total energy is conserved, even as, within the system, energy is continually transferred from one object to another and between its various possible forms. (P-PS5-1AR) **PS3.B: Conservation of Energy and Energy Transfer** ▪ Conservation of energy means that the total change of energy in any system is always equal to the total energy transferred into or out of the system. Energy cannot be created or destroyed, but it can be transported from one place to another and transferred between systems. S2-5) **ETS1.C: Optimizing the Design Solution** Criteria may need to be broken down into simpler ones that can be approached systematically, and decisions about the priority of certain criteria over others (trade-offs) may be needed. (P5-ETS1-1)	**Cause and Effect** ▪ Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects. (P-PS2-4, P-PS2-5) ▪ Cause and effect relationships can be suggested and predicted for complex natural and human designed systems by examining what is known about smaller scale mechanisms within the system. S2-4, P-PS2-5) **Interdependence of Science, Engineering, and Technology** ▪ Science and engineering complement each other in the cycle known as research and development (R&D). Many R&D projects may involve scientists, engineers, and others with wide ranges of expertise. S5-2AR, TS1-1)

Specific Learning Outcomes/Including Evidence Statements:

Observable features of the student performance by the end of the lesson:		
1	Identifying the problem to be solved	
	a	Students analyze a major global problem. In their analysis, students:
		i. Describe* the challenge with a rationale for why it is a major global challenge;

		ii. Describe*, qualitatively and quantitatively, the extent and depth of the problem and its major consequences to society and/or the natural world on both global and local scales if it remains unsolved; and
		iii. Document background research on the problem from two or more sources, including research journals.
2.	Defining the process or system boundaries, and the components of the process or system	
	a	In their analysis, students identify the physical system in which the problem is embedded, including the major elements and relationships in the system and boundaries so as to clarify what is and is not part of the problem.
	b	In their analysis, students describe* societal needs and wants that are relative to the problem (e.g., for controlling CO_2 emissions, societal needs include the need for cheap energy).
3.	Defining the criteria and constraints	
	a	Students specify qualitative and quantitative criteria and constraints for acceptable solutions to the problem.

Prior Student Knowledge:

HS-PS2-6. **Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials. *** [Clarification Statement: Emphasis is on the attractive and repulsive forces that determine the functioning of the material. Examples could include why electrically conductive materials are often made of metal, flexible but durable materials are made up of long chained molecules, and pharmaceuticals are designed to interact with specific receptors.] [*Assessment Boundary: Assessment is limited to provided molecular structures of specific designed materials.*]

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Obtaining, Evaluating, and Communicating Information Obtaining, evaluating, and communicating information in 9–12 builds on K–8 and progresses to evaluating the validity and reliability of the claims, methods, and designs. · Communicate scientific and technical information (e.g., about the process of development and the design and performance of a proposed process or system) in multiple formats (including oral, graphical, textual and mathematical).	PS2.B: Types of Interactions · Attraction and repulsion between electric charges at the atomic scale explain the structure, properties, and transformations of matter, as well as the contact forces between material objects.	Structure and Function · Investigating or designing new systems or structures requires a detailed examination of the properties of different materials, the structures of different components, and connections of components to reveal its function and/or solve a problem.

Possible Preconceptions/Misconceptions:

Misconception: Some students may think “heat” is simply turning into “electricity”.

- ***Metals’*** electrical properties are ***largely unaffected*** by changes in temperature, while ***semiconductors’*** electrical properties ***vary greatly*** with changes in temperature.
- Electrical charge flows along a path of least resistance.
- Changes in electrical resistance in a circuit will cause the electrical charges within the circuit to move, causing a detectable electric current.
- Heat is not a form of energy. Heat is the transfer of thermal energy.
- Temperature is not a form of energy. Temperature is a description of the kinetic energy of particles resulting from the concentration of thermal energy.

LESSON PLAN – 5-E Model

ENGAGE: Opening Activity – Access Prior Learning / Stimulate Interest / Generate Questions:

Let's **brainstorm** where heat is a byproduct of energy use. Have students brainstorm in small groups and/or large groups about different places in their lives where they encounter waste heat. As a class, discuss their answers, and when they mention automobiles or other forms of transportation, transition into today's activity.

Today's activity: Automobiles produce a large amount of heat generated by the burning of gasoline. Most of the energy produced is not used to power the automobile, but is lost as heat. Is there a way to use this wasted heat energy? If so, how can we make a device capable of turning this heat back into usable energy.

Article on the design and use of thermoelectric generators:
https://www.sciencedirect.com/science/article/pii/S135943111501128X

We can use Thermoelectric power generators to produce electricity to power various electrical devices in your car.

Teachers, watch these videos to help you understand today's activity. After the students perform the activity, you can choose which videos you want to show to help them understand how Thermoelectric generators work.

YouTube Video on the Thermoelectric Generator Kit https://www.youtube.com/watch?v=vETXr9WGMac&feature=youtu.be

For both Students and teachers: Thermoelectric power generation Thermoelectric power generation using a Tellurex Z-max thermoelectric module. By applying heat, we create a temperature difference across the two services of the thermoelectric module, resulting in enough power to energize the light connected to the Thermoelectric module.
https://www.youtube.com/watch?v=YhynSkFIJOs

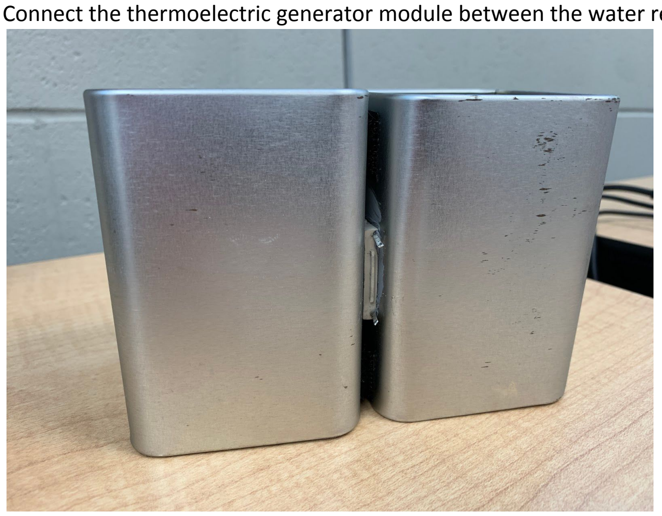
Download Link for Vernier Logger Lite: https://www.vernier.com/products/software/logger-lite/

EXPLORE: Lesson Description – Materials Needed / Probing or Clarifying Questions:

Part II: Generating an Electrical Current

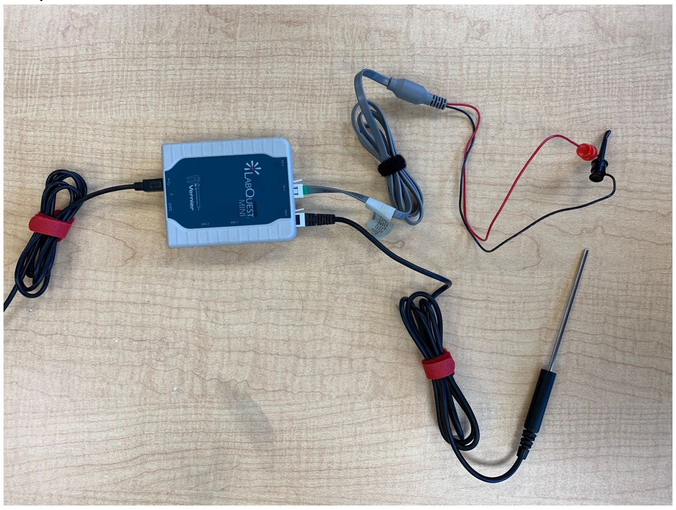
1. Students should read and **annotate** the following article (give students a printed copy) and complete the attached **graphic organizer**(also a printed copy) before beginning the second section of the activity:
   https://www.sciencedirect.com/science/article/pii/S135943111501128X
   https://docs.google.com/document/d/1BPJTmzKGvHnqmB8B6tvQ_seJNPoEnYGil4py4iBSh3o/edit?usp=sharing

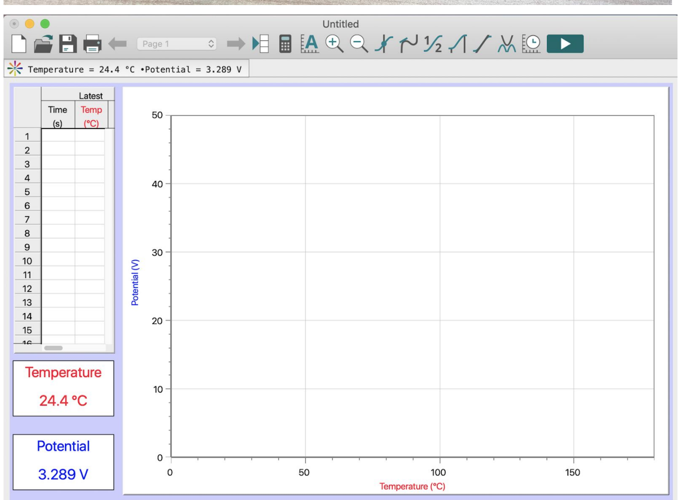
2. Connect the thermoelectric generator module between the water reservoirs as shown.



University of Arkansas POETS, 2019.

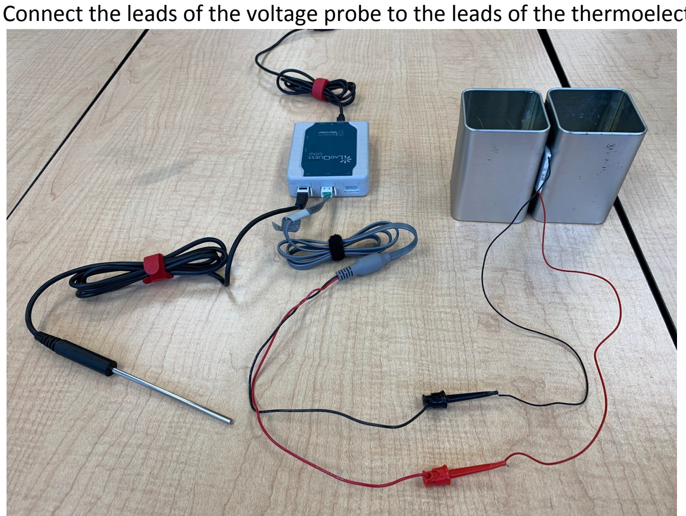
3. Connect a temperature probe and a voltage probe to the data collection device. Set the device to collect voltage as a function of temperature as shown.





4. Fill one can with hot temperature water. Fill a second can with ice water.

5. Connect the leads of the voltage probe to the leads of the thermoelectric generator as shown.



6. Collect temperature and voltage until the ice melts in the ice water. Be sure to stir the water in each beaker regularly to maintain uniform temperatures.

7. Produce a graph of the data. Perform a linear fit with the graph data. The slope of the linear equation is known as the Seebeck coefficient. Record the Seebeck coefficient.
8. Have students record their data and graph. Compare Seebeck coefficients to evaluate the activity's precision among the different lab groups. Discuss any variations that may occur, and brainstorm on their causes.

Materials:

Computer graphing program (Vernier Logger Pro is referenced. Alternatively, Microsoft Excel, Google Sheets, etc. can be used to input data manually)
1 – Vernier Voltage Probe (Alternatively, a multimeter can be used with manual data input)
1 – Vernier Temperature probe (Alternatively, a thermometer can be used with manual data input)
1 – Hot water source (hot plate, etc)

EXPLAIN: Concepts Explained:

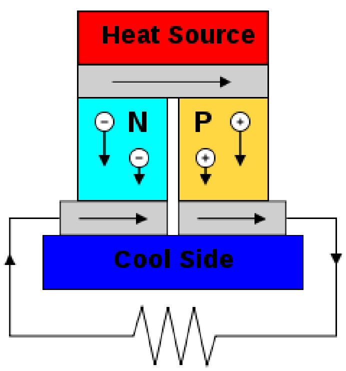
For Students after the activity:

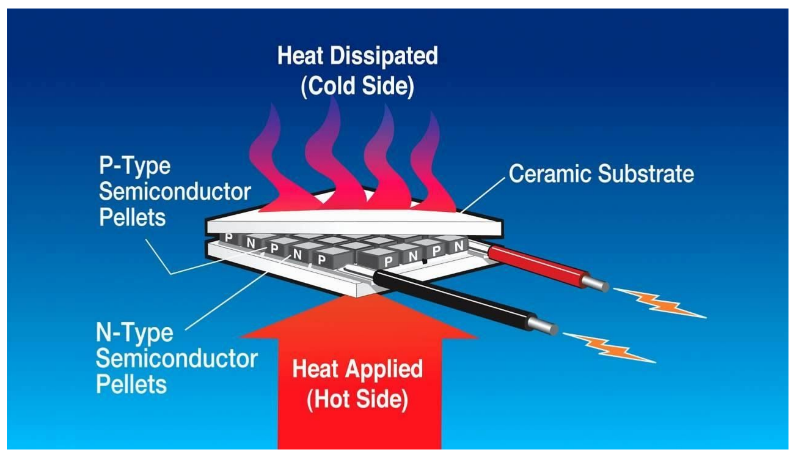
1. **What trends do you see in your data?**
2. **Compare your data with data from other groups.**
3. **As a class, do you see the same trends?**
4. **Why is thermal energy moving across the generator able to generate electrical energy?**

For the teacher:
The Thermoelectric (TE) phenomenon was first discovered by Tomas J. Seebeck in 1822, when he developed a voltage by joining two pieces of different materials together and placing a temperature difference to the couple. He also found that the voltage difference observed was proportional to the temperature gradient.

In a TE power generation device, one branch of *p*-type narrow band gap semiconductor connects with another branch of *n*-type narrow band gap semiconductor with metallic contacts. In thermoelectric materials, both holes in the *p*-branch and electrons in the *n*-branch can carry heat. Therefore, when a temperature gradient forms between the two branches, both electrons and holes will be driven in the same direction resulting in an electric current within the circuit. This is the basic mechanism for thermoelectric power generation. (From the thesis by Xiaopeng Qiu and Introduction to Nanostructured Thermoelectric Materials by Prof. Greg Salamo, University of Arkansas)

Thermoelectric Generator is an experimental kit which demonstrates the direct conversion of heat into electrical energy using the Seebeck effect.





In the previous lesson in this series, students learned that semiconductors' electrical resistance is dependent on temperature. Since the thermoelectric generator module consists of two different types of semiconductors, an electrical resistance gradient grows as a temperature gradient increases. Since electrical current follows a path of least resistance, thermal energy moving across the generator is sufficient to set electrons within the generator module in motion and generate an electric current.

Vocabulary:

Voltage
Thermal Energy
Conductor
Insulator
Semiconductor
Gradient
Generator
Waste Heat
Temperature
Electricity
Power

ELABORATE: Applications and Extensions:

Power optimization is important in industry. Auto manufacturers are constantly looking for ways to make engines more powerful and efficient. Computer manufacturers are seeking ways to cut bulky cooling systems.

- Challenge the students to determine ways of harnessing the lost energy of wasted heat. Have students create a presentation that outlines the optimization of an existing technology by using the thermoelectric generator.

The relationship between thermal and electrical energy flow in a thermoelectric generator works both ways. Connect a low voltage power supply to the leads of the thermoelectric generator module. DO NOT exceed 12 V! Doing so will damage the thermoelectric generator module.) One side of the generator will become warm, and the reverse side will become cold. Challenge students to explain this phenomenon.

- Can We Make Ice?
  YouTube Link on Peltier Cooling:

https://www.youtube.com/watch?v=rT9-HUzUqhQ

Allow students to apply and extend at your discretion with these ideas.

EVALUATE:
Formative Monitoring (Questioning / Discussion):

1. How do semiconductors differ from metals in terms of their electrothermal properties?
2. Do we think all semiconductors behave exactly the same?
3. The thermoelectric generator consists of two different types of semiconductors. Why might this matter?
4. What does thermal energy seem to cause atoms and molecules to do?
5. What exactly is electric current?
6. Summarize how the thermoelectric generator works.

Summative Assessment (Project Extension):

1. Create a presentation (Google Slides, Poster, etc) to explain how you could solve the problem assigned to you using a thermoelectric generator. The presentation needs to be in CER/J (Claim, Evidence, Reasoning/Justification) format.
PROVIDE THIS C-E-R TEMPLATE AND RUBRIC
https://docs.google.com/document/d/1Qk5x6X_GYrWybntWNdedC7ZZPjCa71QfWP1NwifkTxo/edit?usp=sharing

a. In an air conditioning unit, much of the energy associated with the system is lost to its surroundings as waste energy. Explain how you could use a thermoelectric generator to “turn” the waste energy into usable energy.
b. A refrigerator is used to keep substances at a particular temperature to keep them from spoiling or at least slow down the process of the food spoiling. The temperature is typically lower than the temperature outside of the refrigerator. Through this process of cooling air inside the refrigerator, energy is given off to the surroundings as heat. How could you use a thermoelectric generator to “turn” the waste energy into usable energy.
c. In a car engine, the energy from a combustion reaction is converted and used to move the car. During this process, much of the energy created is lost as thermal energy to the surroundings. How could you use a thermoelectric generator to “turn” the waste energy into usable energy.
d. Have you ever opened a dishwasher to unload it and were greeted with a steam facial? A dishwasher is a very convenient appliance that makes cleaning dishes so much faster. A lot of Thermal Energy is produced and given off during this process. How could you use a thermoelectric generator to “turn” the waste energy into usable energy?
e. A clothes dryer is an appliance that speeds up the clothes drying process. This convenience is also very costly in comparison to other household appliances. Thermal energy is produced to dry the clothes. How could you use a thermoelectric generator to capture any lost thermal energy and “turn” into usable energy?
f. Computers ease our workload in so many ways. Computers can do things in a matter of seconds, and save us so much time. In doing so, much of the energy that is involved in these processes are lost as thermal energy to the surroundings. How could this “waste” energy be recaptured and ” turned” into usable energy for the computer?
g. Televisions are a great source of entertainment. Televisions use electrical energy to produce the picture that is viewed. Some of the electrical energy is used, but some of the energy is lost to the surroundings in the form of thermal energy. How could a thermoelectric generator be used to capture this waste energy and convert it into usable energy for the television?
h. A new popular appliance in the kitchen is the Instant Pot. This device allows you to cook meals in a fraction of the time that it would normally take to cook. The Instant Pot does this through the use of pressure. The pressure is allowed to build up due to electrical energy becoming thermal energy and that energy being applied to a constant volume. When the cooking is complete, the pressure has to be released, either naturally by the device or manually. The pressure is released by allowing the steam that was generated during cooking to escape. A lot of steam is released, bringing with it a lot of

thermal energy. How could you use a thermoelectric generator to convert this waste thermal energy to usable energy for the Instant Pot?

i. Gaming systems are extremely popular today. These systems are how a lot of people spend most of their time. As the system is used, the equipment becomes very hot, indicating that some of the electrical energy that is being supplied is lost as thermal energy to the surroundings. How could you use a thermoelectric generator to convert this lost thermal energy to usable energy for the system?

j. A generator is a device that uses mechanical energy to produce electrical energy. A generator is typically used when there is a power outage. A generator allows daily activities to continue even in the event of a power outage. During operation, some of the energy that is supplied is converted to electrical energy, but a lot of the energy supplied is lost as thermal energy to the surroundings. What if this waste energy could be captured, converted, and become usable energy for the generator? How could you use a thermoelectric generator to capture and convert this lost energy?

Optional: Utilize a Gallery Walk for students to share and view each other's projects

Materials Required for This Lesson/Activity (per class of 20 divided into pairs)			
Quantity	**Description**	**Potential Supplier (item #)**	**Estimated Price**
1 per district	Vernier Logger Pro	Vernier Science and Technology	$250 site license
1 per district	Vernier Logger Lite (limited, but free, alternative to Logger Pro)	Vernier Science and Technology	Free
10	LabQuest Mini Interface	Vernier Science and Technology	$140 ea.
10	Voltage Probe	Vernier Science and Technology	$12 ea.
10	Temperature Probe	Vernier Science and Technology	$29 ea.
	Hot water source		
	Ice		
1 set of 10	Thermoelectric Generator Kits	http://shop.miniscience.com/navigation/detail.asp?ID=KITTEG	$210 for 1 set of 10
3	1.7 Liter Stainless Steel Electric Kettle MODEL: 40989	https://www.hamiltonbeach.com/1-7-liter-stainless-steel-electric-kettle-40989	$29.99