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Off the Grid Unit

Lesson 6: Biolite – Fire to Phone Charging

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DESCRIPTION: This is the 6th part in the Off the Grid Unit. This lesson continues to look at the **efficiency** of USB charging devices, but this time we will be using a commercially available camping stove that uses heat to create electricity in order to charge a phone. This is the **Biolite** stove that exploits the **Peltier Junction** in order to generate an electrical current. Students can also attempt to measure power output of the stove by taking data on the heating **of water**. This is a demonstration activity, as the whole class will be using one stove and recording data into their science journals.

GRADE LEVEL(S): 7-8 or 9-12

SUBJECT AREA(S): Energy fundamentals, electrical circuits, **efficiency,** thermo-electric effect, calories and heat

ACTIVITY LENGTH: 1 day or 1-2 hours

LEARNING GOAL(S):

1. Students will use thermometers and a stopwatch to calculate power.
2. Students will use collected data and be able to make power calculations from this data.
3. Students will also be able to calculate **efficiency** from their **power** calculations.
4. Students will be able to compare **efficiencies** to other circuits tested in this unit.
5. Students will know what the Peltier Junction does.

NEXT GENERATION SCIENCE STANDARDS:

- HS-PS3-1. Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system are known.

COMMON CORE STATE STANDARDS:

- N-Q 1. Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays.

- N-Q 2. Define appropriate quantities for the purpose of descriptive modeling.

Materials List

- Timer, clock or stopwatch
- Thermometer
- **Biolite** camp stove
- USB current/voltage meters
- Cell phone or device that uses a USB plug for charging – students can bring in a USB charging cord for their phone, or instructor can supply any USB charging device. I used LED bike taillights that charge with a USB.

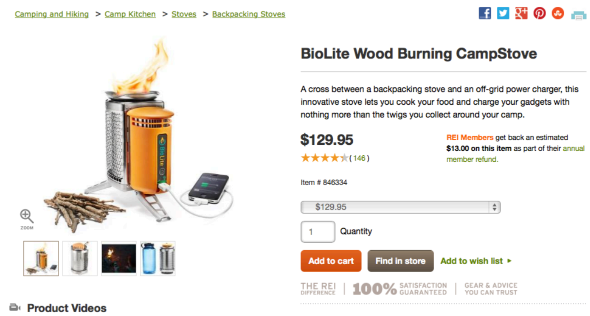

Figure 1. BioLite Camp Stove.

Other Supplies

Student Journals

Vocabulary

- Peltier Junction
- Power: P = VI
- Efficiency: $e = P_{out}/P_{in}$
- Specific Heat
- Temperature Differential
- BioLite
- Thermoelectric effect

Lesson Details

Planning and Prep

This is meant to be the 6th lesson in the **Off the Grid Unit.** This lesson can be a stand-alone as well. It is a good example of severely limited efficiency, probably a fraction of a percent! It is also a good example of taking a crude form of energy (Heat) and without any moving parts creating a very refined form of energy (Electricity) to charge your phone.

You will need the **Biolite** stove, lots of small sticks and a USB charging device with cord to plug into the stove. You will want to do this outside, as it is smokey until it gets going and you want to feed it frequently so it doesn't smoke as much. Trial runs are a good idea. Fir cones and wood chips are excellent fuel.

Student Background

Students participating in this lesson should be familiar with calculating **Efficiency** and **Energy Transformations.**

Educator Background

Educators leading this lesson should be familiar with the following:

- *The **Thermoelectric** Effect - **Biolite** Stove:* This would most likely be a class demo where each group gathers data from the USB meter on the output of the **Biolite** camp stove to charge a phone, and then the class will need to come up with a value for the Power of the heat input. This could be done by using the manufacturer's data of 2-4 KiloWatts, or if you would like to explore the physics the students could try to measure the energy gain in a pan of water over a given amount of time – for example, measure out a liter or water into a steel tea pot, measure the temperature of the water, fire up the stove, wait until it is charging, then put the water on. Measure the temp every 30 seconds, while also measuring the output to the cell phone through the USB meter – continue until boiling is reached.
- If you are going to try to measure the power of this device, you only need to keep track of temperature and time as the water heats up. You will also want to start with a set amount of water, though you will no doubt lose some to vapor by the time you boil the water. The Power calculation is simple Physics, and students should at least be able to plug in the numbers into the formulas and churn out a value. Note that the manufacturer's spec state that the stove is capable of 4-5 Kilowatts! This will vary tremendously depending on success of each variable
- The steps below outline the process in which students can calculate efficiency:
    - To find the energy the water transformed from the stove, students will need to use the specific heat of water, as well as the specific heat of the teapot – most likely stainless steel. They will also need to know the mass of water, and teapot. They can multiply:
    - (the mass of the object - in grams) (the specific heat of the object)(change in temperature in C) = Energy absorbed by the water or teapot

Lesson sequence

This Lesson can be completed in one 2-hour class period or two shorter periods. As this is a demo lesson, much of the valuable time will be spent in discussion. Start the lesson introducing the Biolite stove as yet another way to charge a USB device. Students should already be interested in how its efficiency compares to other devices previously studied.

Before starting the demonstration, students should create data tables in their Journals (example below). Depending on your class organization, you can make this activity fairly inquiry-driven by students by having them design the data tables and make clear the assumptions and simplifications that they will have to make to determine the efficiency of the Biolite. Some of this could be completed before the day of the demonstration itself.

Description of Device Tested	Cell Phone side of circuit					Biolite Stove Power *
	Voltage	Current	Power P_{out}	Efficiency(%) $(P_{in}/P_{out}) \times 10^2$		Power P_{in}

*Manufacturer states 4-5 KW

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Once students are ready for data collection (teacher note: if they aren't designing the data tables, have them copy the table down in their Journals first thing, and hold most of the discussion outside while the Biolite is getting going. I definitely recommend practicing with it beforehand to get a sense of the timing for the device!)

Example Calculations: Note that students could come up with these calculations before the actual demonstration, and then redo the calculations with actual values.

- Assumption(s)
    - We will assume the teapot is also heated from beginning water temp to 100°C.
- Initial Condition(s)
    - Water temperature = 20 °C
    - Water volume = 1 L
- Defined Values
    - $Specific\ heat\ of\ water = \frac{4.186\ J}{gram \cdot ℃}$
- Calculations for heating water
    - Change in water temp, $\Delta T = 100\ ℃ - 20\ ℃ = 80\ ℃$
    - $Mass\ of\ water\ =\ 1\ Liter \times \frac{1000\ cm^3}{1\ L} \times \frac{1000\ g}{1000\ cm^3} = 1000\ grams$
        - (Note: the specific heat is defined in grams so we must match that unit. This is one method of performing this dimensional analysis. Students could also use dimensional analysis to express the specific heat of water in Joules/(Liter-°C))
    - $Energy\ absorbed =\ \Delta T \times Mass \times Specific\ Heat$
    - $Energy\ absorbed = 80\ ℃ \times 1000\ grams \times \frac{4.186\ J}{grams \cdot ℃} = 334{,}880\ Joules$
    - $\Delta E_{Water} = +\ 334{,}880\ Joules$
- If we assume that both the teapot and the water heat up to 100 °C, how much energy was absorbed by the teapot?
    - Assume mass = 500 g
    - Assume initial T_{teapot} = initial T_{water} = 20 °C
    - Assume stainless steel specific heat ≈ $\frac{0.5\ J}{gram \cdot ℃}$
    - $Energy\ absorbed\ by\ teapot = 80\ ℃ \times 500\ grams \times \frac{0.5\ J}{grams \cdot ℃} =\ 20{,}000\ Joules$
    - $\Delta E_{Teapot} = +\ 20{,}000\ Joules$
    - It is surprising that while the teapot has half the mass of the water ($M_{Teapot} = 0.5 M_{Water}$), it only requires 1/16th the energy to heat to 100 °C. This offers the opportunity for some conversations about the role of the oceans in climate change.
- Total Energy Absorbed by System, $\Delta E =\ \Delta E_{Water} + \Delta E_{Teapot} = 354{,}880\ J$
- Discuss with students whether this represents all of the energy moving through the system. Were the sticks being used to burn in the BioLite release exactly 354 kJ? – Certainly there is a lot of energy escaping the system as heat, as you can tell by placing your hand near the BioLite!

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- Students are welcome to discuss how they could calculate efficiency; bring the conversation back to one about modeling: models are inherently inaccurate because they are simplifications of reality, but they are very useful tools. Work with the class to decide that efficiency calculations will assume 100% energy transfer from the sticks to the water.

- Now we can find efficiency in two ways:
  1. By knowing how many seconds it took to boil the water, we just divide energy by this time to get average power and compare that to the average power from the USB data to get efficiency.
  2. We could also measure the energy the phone received (Power x time) and by dividing E_{out}/E_{in} we would also have efficiency.
- Calculating Efficiency:
  - Efficiency = $E_{out}/E_{in} = P_{out}/P_{in}$
  - Step 1: Calculate Power input
    - Assumption: 100% of energy in sticks used for boiling water
    - Assumption: it took 5 minutes to boil the water
      - Calculation: $5\,min \times \frac{60\,seconds}{min} = 300\,seconds$
    - $P_{in} = \frac{Energy}{Time} = \frac{354{,}880\,J}{300\,sec} \approx 1183\,\frac{J}{s} = 1183\,W \approx 1.18\,kW$
  - Step 2: Calculate Power output
    - As this is a demo, we only use one USB meter attached to one device. If students were powering different devices in the lab, consider allowing them to plug in their devices for this demo.
    - Students will record voltage and current into the USB device (e.g. phone) and calculate power into the phone, P_{out}, remembering that $P = I \times V$
  - Step 3: Calculate efficiency! Expect values <1%.

After students have calculated their efficiencies, have them compare their values with other groups and answer the following questions:

1. How does this method of charging your phone compare to other methods we have experimented with? Rank it according to efficiency.
2. Despite the terrible efficiency of this method, give an example where this might be the preferred method for charging your phone.

Lesson Extensions

You can go into the physics of how to measure power by tracking how fast a given quantity of water changes temperature to try to measure power directly. Of course you will also need to account for the vessel the water is heating in, as well as trying to measure how much heat is escaping the system without heating the water.

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