

Laboratory Exercise: The *SI* Unit for Energy

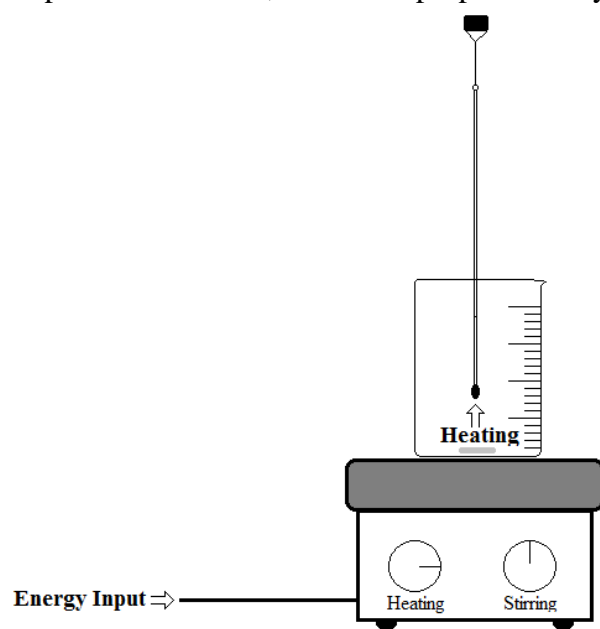
In this exercise we will determine the efficiency with which the energy consumed by a hotplate is used to heat a beaker of water. This exercise will allow us to examine the concept of Energy and the Units associated with its measurement.

Energy is identified as the Work required to move a given mass a specified distance using a given force. The magnitude of the required force is proportional to the acceleration the force imparts on the mass; where the proportionality is the mass itself. A greater force is required to

accelerate larger masses. In terms of our base SI units, the *SI* unit of energy, designated the joule [J], is derived as:

$$\begin{aligned} 1 \text{ joule} &= \text{force} \times \text{distance} \\ &= \text{mass} \times \text{acceleration} \times \text{distance} \\ &= (\text{kilogram}) \\ &\quad \times ((\text{meter/second})/\text{second}) \times (\text{meter}) \\ &= \frac{\text{kg} \times \text{m}^2}{\text{s}^2} \end{aligned}$$

Thus, the joule is a unit standard derived from the kilogram, meter and second.



Alternatively, energy is identified as the Work required to move charge through an electric potential, measured in the *SI* unit of volts [V]. Since the unit of charge, the coulomb [C], is defined in terms of the electric current delivered in a unit of time, we have:

$$\begin{aligned} 1 \text{ joule} &= \text{charge} \times \text{potential} \\ &= \text{current} \times \text{time} \times \text{potential} \\ &= (\text{ampere}) \times (\text{second}) \times (\text{volt}) \\ &= A \times s \times V \end{aligned}$$

So, we can measure the energy consumed by the hotplate by using our *Kill A Watt EZ* meter to track the power supply's voltage and the hotplate's current draw and a stopwatch to track the time over which the current is drawn:

$$\text{Energy} = \text{Current} \times \text{Time} \times \text{Potential}$$

Finally, this energy is used to heat the Water in the beaker. It was James Prescott Joule who was able to quantify the relationship between the energy as conceived above and the thermal energy required to heat substances. Using our unit convention, he showed that 4.184 joules of energy would heat one gram of Water one degree Celsius. More generally, the thermal energy required to heat a given mass of Water is determined via:

$$\text{Energy} = \text{Mass Water} \times \left(4.184 \frac{\text{J}}{\text{g} \text{ } ^\circ\text{C}}\right) \times (\text{Final Water Temp.} - \text{Initial Water Temp.})$$

Now, it is true that not all the energy consumed by our hotplate will be used to heat the Water. There are plenty of energy losses evident; heat lost to surroundings, heat used to warm the beaker and thermometer, etc. The efficiency of heating the Water with our hotplate will be less than one hundred percent and can be determined via:



James Prescott Joule

$$\text{Efficiency} = \frac{\text{Energy Used Heating Water Only}}{\text{Energy Consumed by Hotplate}} \times 100\%$$

Thus, we will measure the energy consumed by the hotplate during the heating of the Water, calculate the energy required to heat just the Water and the energy efficiency of this process. In doing these calculations we will have to very carefully track all the units of measurement through our calculations, which is the point of the exercise.

Procedure

You may want to examine the example data/calculation in the Data Analysis section before you begin. This should help to familiarize you with the type of data needed for the energy calculations.

1. Obtain a Hot Plate/Stir Plate combination and make sure the Heat and Stirring dials are set to zero. Plug the *Kill A Watt EZ* meter into a nearby power outlet and plug the hotplate into the meter.
2. Use the meter to make a voltage reading for the power supply.
3. Place a 600 mL Beaker on the hotplate and fill the beaker with 500 mL of distilled Water. Use a large graduated cylinder to measure out the Water with some precision.
4. Add a stir bar to the Water and hang a stem thermometer from a clamp into the Water to its immersion mark. Wait at least 10 minutes and then make a temperature reading.
5. Set the *Kill A Watt EZ* to make current readings.
6. Marking the time as zero, simultaneously turn on both the Heating (200°C) and Stirring (11) and make an amperage reading.
7. **Every minute or every time the hotplate turns on or off** make an amperage reading. (If you are making a reading because the hotplate has turned On/OFF, make a note of this event.)
8. Continue heating the Water until its temperature rises to 60°C. Make one final amperage reading before you turn off the heating and stirring.

Data Analysis

Calculate the Energy Consumption of Your Hot Plate

Block Out the Times Where the Hot Plate is "On" or "Off". Use the Average Current During each Block to Determine the Energy Consumption During that Block. Then Add the "Block" Energy Consumption to Determine the Total Energy Consumption.

Example:

...
24.0 s 0.24 A
31.5 s 6.10 A ON
67.1 s 5.98 A
85.4 s 0.23 A OFF
...

$$I_{\text{av}} = (6.10 \text{ A} + 5.98 \text{ A}) / 2 = 6.04 \text{ A}$$

$$\text{Energy} = 6.04 \text{ A} \times (85.4 \text{ s} - 31.5 \text{ s}) \times 120.5 \text{ V} = 3.92 \times 10^4 \text{ J}$$

Calculate the Energy Required to Heat the Water

Calculate the Efficiency of Heating the Water with this Hotplate

Take the density of Water to be 1.00 g/mL and determine the Water's mass via:

$$\text{Mass Water} = (1.00 \text{ g/mL}) \times \text{Volume Water}$$

Post Lab Questions:

1. Some of the energy supplied to the hotplate is used to rotate the stir bar. Where does this mechanical energy go to?
2. An older unit of thermal energy is the calorie. How was the "15° calorie" defined? How is the current calorie defined? What is the reasoning behind the current definition?
3. Suppose our thermometer reads systematically too high by 0.5°C. How will this affect our results? Explain.
4. What is the reported accuracy for the voltage reading of the *Kill A Watt EZ* meter?
5. How much did it cost ust to buy the energy we used to heat our beaker of Water? (Hint: Our power is supplied by the Socorro Electric Coop. Their website lists the General Service Rate for power. Note: they use kilowatt hours [kWh], a billing unit of energy, for energy measurements.)

$$1 \text{ kWh} = 3600000 \text{ joule}$$

$$\# \text{ kWh} = \# \text{ joules} \times \left(\frac{1 \text{ kWh}}{3600000 \text{ joule}} \right)$$

6. How is the volt defined in terms of *SI* base units?
7. `How did James Prescott Joule measure the mechanical energy equivalent of heat? In what unit did he report his result? (Hint: Do a short *wiki* search of his bio.)