Name: _____ Date: _____ Period: _____

Energy Harvesting Worksheet Answer Key

Recall that $E = \frac{1}{2}C(V_2^2 - V_1^2)$. C given on the capacitor is in microfarads (μF). To convert to farads (F), divide by 1,000,000. When farads are multiplied by volt^2, the units come out as joules.

1. Calculate how much energy was used to power the LED.
   - Voltage before flipping the switch ($\mathbf{V_2}$): Results will vary depending on capacitor and LED used
   - Voltage after flipping the switch ($\mathbf{V_1}$):
   - Energy used by the LED:

$$\boldsymbol{E = \frac{1}{2}C(V_2^2 - V_1^2)}$$

2. Some piezoelectric generators are used to charge batteries so that the energy can be used later. Figure out how long it would take to charge your laptop using the piezoelectric generator built in class. **An average laptop battery can store 220,000 joules**.
   a. How much energy does your generator store per tap.
      - Voltage measured before tap ($\mathbf{V_1}$): Results will vary depending on capacitor and LED used
      - Voltage measured after a single tap ($\mathbf{V_2}$):
      - Energy stored per tap: Should be close to this, but answers will vary. The following equations should be used.

$$\boldsymbol{E_{tap} = \frac{1}{2}C(V_2^2 - V_1^2) \approx 0.00002\ joules\ per\ tap}$$

   b. How many taps will it take to charge the battery (to generate 220,000 joules)?

$$220{,}000\ joules \Big/ E_{tap} \approx 1.1 \times 10^{10}\ taps$$

   c. If you can tap your piezoelectric element 5 times per second, how long would it take to charge your laptop?
      - In seconds:

$$number\ of\ taps \Big/ taps\ per\ second = 1.1 \times 10^{10} \Big/ 5 = 2.2 \times 10^{9}\ seconds$$

      - In hours:

$$2.2 \times 10^{9} seconds \Big/ 3600\ seconds\ per\ hour = 611{,}111\ hours$$

- In days:

$$611{,}111\ hours / 24\ hours\ per\ day = 25{,}463\ hays$$

- In years:

$$25463\ days / 365\ days\ per\ year = 69.8\ years$$

3. Repeat questions 2b and 2c for an **AA battery that stores 10,000 joules**.
   Expect students to use the same equations as in question 2, but replace the 220,000 joules with 10,000 ,oules starting in 2b
   - Number of taps:
     500,000,000
   - Seconds to charge:
     100,000,000 seconds
   - In hours:
     27,778 hours
   - In days:
     1,157 days
   - In years:
     3.2 years

4. Now that you have calculated how long it takes to generate enough energy to charge some common batteries, one way that engineers increase the rate of energy "production" in piezoelectric generators is by strategically placing the piezoelectric materials where they undergo a large quantity of deformations very rapidly. **Think about this as a way to improve your setup. List two places you could locate your piezoelectric generator in your everyday routine that would help it convert energy at a much higher rate. (Assume that any motion will work to deform the piezoelectric element; it does not necessarily need to be tapped directly.)**

   Expect students to come up with a number of answers to this question. The idea is to get them thinking about what they do every day that requires/generates a lot of movement. This could be something like attaching the devices inside a basketball or soccer ball during practice, placing them on the end of a band instrument where the sound waves come out, putting them on a pencil while taking a test, and so on. It may help to provide a few examples like these to get them started.