3.1) ENERGY MEASUREMENT

Objective: This laboratory exercise will show you how to measure the relation between the energy applied and the task that is accomplished. This serves as a basis for discussing more efficient ways to convert energy. **Video instructions:** https://vimeo.com/69413184, https://vimeo.com/69829763, and https://vimeo.com/113010154

Introduction: The energy spent to accomplish a task can be divided into two components; work and dissipated heat. Work includes any non-random movement of particles such as flowing water and electric current. Consequently, dissipated heat is regarded as the "energy graveyard" that undermines the efficiency of all appliances. This is attributed to the second law of thermodynamics, whereby all reactions generate chemical disorder (entropy) and waste heat is the means whereby exothermic reactions release entropy to the surroundings. This principle guarantees that no process can ever be 100% efficient, no matter how much waste heat is minimized through lubrication and improved design.

Light is another form of work energy, and in 1839 French physicist Edmond Becquerel observed that exposure to sunlight caused certain materials to produce a measurable electric current. During the 1950s, American researchers revisited this phenomenon to develop practical photovoltaic cells that could power orbiting satellites indefinitely.

Due to their high cost, photovoltaic panels made up less than 0.1% of grid-connected electricity produced in the U.S. in 2008. However, government incentives and sharp declines in cost have increased this share to 1.2% in 2014 (*1*). Photovoltaic panels are the most common form of alternative energy in residential areas because they are quiet and require almost no maintenance. This trend may accelerate as average price of photovoltaics continues to fall and more electric companies use "reverse metering" to buy up surplus electricity produced by households with solar panels.

Literature Cited:

1. National Renewable Energy Laboratory. 2014. *Renewable Energy Data Book.* p 24. Accessed on June 17, 2023. http://www.nrel.gov/docs/fy16osti/64720.pdf

Procedure A: Efficiency of Using Electricity to Heat Water

1) Place 500 mL of water and the thermometer into the chosen heat source.

2) Plug your wattmeter into the wall then plug the heat source into the wattmeter with the heat turned off.

3) Set the wattmeter to read kilowatt-hours, making sure you are starting at "zero" (reset if necessary).

4) Record the initial temperature then turn on the heat to the maximum setting.

5) Read the wattmeter and turn off the heat source as soon as the wattmeter reads 0.04 kilowatt-hours (this is equivalent to 40 watt-hours).

6) Record the final temperature and do the following calculations: (assume 1 mL water = 1 gram)

a) (g water) × (4.2 J / g °C) × (final temperature – initial temperature) = Joules of heat absorbed

example: (500 g water) × (4.2 J / g × °C) × (70°C – 20 °C) = **105,000 J**

b) (Watt-hours consumed) × (3600 J / watt-hour) = Joules electricity consumed

example (J electricity consumed): (50 Wh) × (3600 J/Wh) = **180,000 J**

c) (Joules heat absorbed) ÷ (Joules electricity consumed) = efficiency ratio

example (% efficiency): (105,000 J) ÷ (180,000 J) = 0.58 = **58%**

Procedure B-1: Pulling Up a Mass Using Rotary Motion

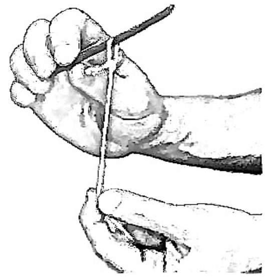


Fig. 1

1) Tie one end of the string to the shaft (Fig. 1).

Fig. 2

2) Tie the other end of the string to a 60 gram mass (Fig. 2).

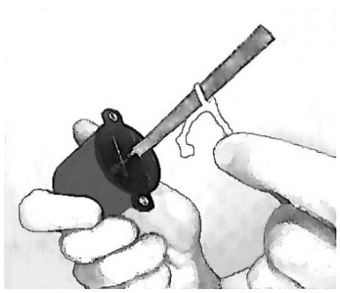


Fig. 3

3) Install the shaft on the motor (Fig. 3) and hold the motor on the edge of a table (Fig. 4).

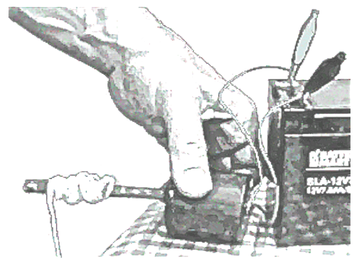


Fig. 4

4) Connect the motor terminal leads to the battery to pull up the mass (Fig. 4).

Procedure B-2: Measuring Efficiency of Rotary Motion

1) Measure the length from the floor to the axle.
2) Measure electricity consumed and convert to Joules using these two equations;

   Volts × Amps = Watts and Joules = Watts × seconds

   a. If you only have a multimeter:
      i. Set up your multimeter for measuring amps and measure the seconds needed for the mass to travel from the floor to the table. There is no need to measure volts because battery voltage is usually constant.
      ii. Use the following equation to calculate the energy consumed by the motor:

      Volts × Amps × (average seconds) = Joules electricity consumed

      example: (12 V) × (0.50 A) × (33 s) = 198 J

   b. If you have a direct current watt meter:
      i. Set up your watt meter to measure the amp hours. There is no need to measure volts because battery voltage is usually constant.
      ii. Use the following equation to calculate the energy consumed by the motor:

      Volts × Amp hours × (3600 J/Wh) = Joules electricity consumed

      example: (12 V) × (0.003 Ah) × (3600 J/Wh) = 130 J

3) Use the following equations to calculate the work done by the motor:

Joules = kilograms × meters^2 × seconds^{-2}

9.8 meters × seconds^{-2} = acceleration due to gravity

kilograms × (9.8 meters × seconds^{-2}) × total meters travelled = J work accomplished

example: (0.080 kg) × (9.8 m / s^2) × (0.74 m) = 0.58 J

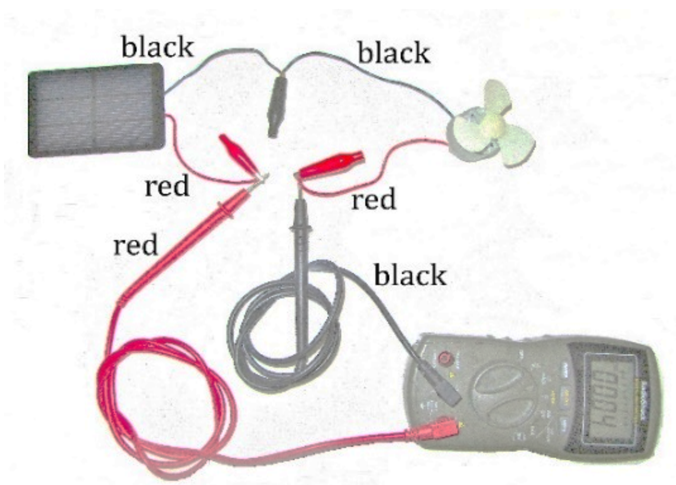
4) Use the following equation to calculate the efficiency of using electricity to accomplish this task:

(J of work accomplished / J of electricity consumed) × 100% = % efficiency

5) Repeat this evaluation for a different speed or mass.

Procedure C: Photovoltaic Dynamics

1a) If you only have multimeters, follow the procedure from i to v



i. Connect the multimeter to measure amps (Fig. 1).

ii. Connect the multimeter to measure volts (Fig. 2)

iii. Fig. 1 & 2 show the two multimeters connected separately, but for this activity they can be connected *at the same* time (Fig. 3).

iv. Take the apparatus outside on a sunny day and record the volts and amps generated.

v. Calculate the watts generated using the formula:

Fig. 1

watts = amps × volt

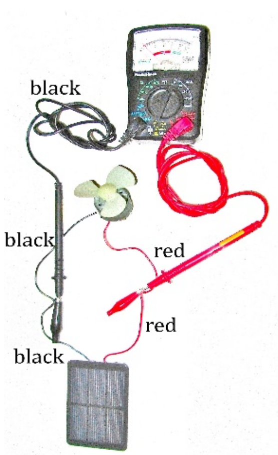


Fig. 2

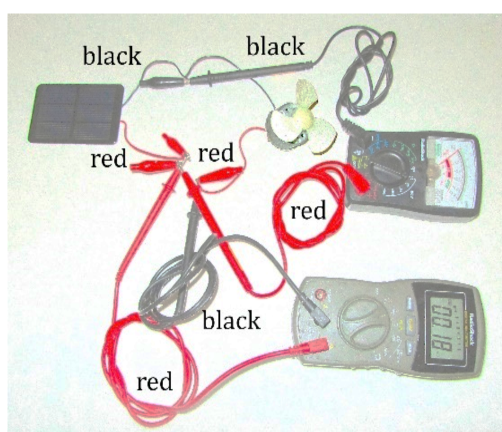


Fig. 3

1b) If you have a DC watt meter (Fig. 4), follow instructions on your watt meter to connect it to your source and load (Fig. 5) then proceed to take it outside to record the watts generated by the sunlight.

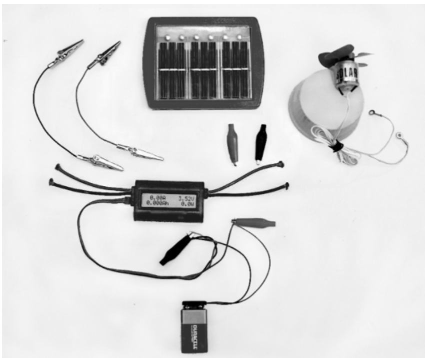


Fig. 4

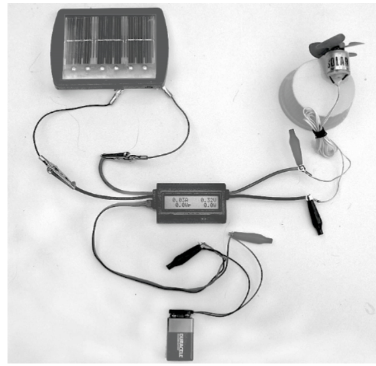


Fig. 5

Calculations for Photovoltaic:

1) Use a ruler to measure the metric dimensions of the photovoltaic cell (you may find it easier to take these measurements in centimeters and divide by 100 in order to convert to meters). Divide the watts generated by the total square meters of the cell. This will give you the energy generated per square meter per hour.

$$\textit{watts generated per } m^2 = \text{watts} \div \text{total } m^2$$

2) A window-unit air conditioner may use on average about 790 watts. Use this information to calculate how many square meters of photovoltaic cells you will need to run this appliance during a sunny day. To do this, use the following equation and solve for the "total" square meters needed:

$$\textit{total } m^2 \textit{ needed} = 790 \text{ watts} \div \text{watts generated per } m^2$$

3) Based on a comparison of retail prices from 2014, the cost of photovoltaic cells can range from \$200-\$650 per m^2. On the basis of an average price of about \$300 per m^2, calculate how much it will cost to purchase enough solar panels to run a window-unit air conditioner on a sunny day. To do this, use the following equation:

$$\textit{total cost} = (\$300 / m^2) \times \text{total } m^2 \text{ needed}$$

4) Residential electricity usage is measured in kilowatt-hours (kWh). Use your latest electric bill to estimate how much it normally costs to run your air conditioner for a six-hour period of time on a given day. To do this, find the *cost per kilowatt-hour* according your electric bill and use the following equation:

$$\textit{total electricity cost per day} = (6 \text{ hours per day}) \times (0.79 \text{ kW consumed}) \times (\text{cost per kWh})$$

5) Suppose your solar panel is located in a sunny climate that allows it to receive an average of six hours of sunlight per day. Assuming that the average price of electricity remains unchanged year after year, calculate how long it will it take for your investment to pay for itself. To calculate this in terms of the 6-hour sunny days, use the following equation:

$$\textit{total days needed} = (\text{total cost of photovoltaic cells}) \div (\text{total electricity cost per day})^*$$

6) Divide the total days needed by 365 days per year to get the number of years needed to break even on your investment.

*The *total electricity cost per day* is equivalent to the *total saved per day* because you are using photovoltaic cells to generate this power that would otherwise be supplied by the grid.

Questions:

1. <u>Heat source A</u>:
    a. How many joules of electricity were consumed to heat the water? (Show work)

    b. How many joules of heat were absorbed by the water? (Show work)

    c. What was the efficiency of heating the water with this set-up? (Show work)

2. <u>Heat source B</u>:
    a. How many joules of electricity were consumed to heat the water? (Show work)

    b. How many joules of heat were absorbed by the water? (Show work)

    c. What was the efficiency of heating the water with this set-up? (Show work)

3. Which set-up was the least efficient for heating water? Explain why it was less efficient.

4. Why is it impossible to obtain 100% efficiency in heating the water? Where else is the heat lost?

5. How many joules of electricity were consumed to pull up the weight? (Show work)

6. How many joules of work were accomplished by pulling up the weight? (Show work)

7. What was the efficiency of transforming the electricity to work? (Show work)

8. Which speed was more efficient?

9. Follow the steps to calculate the total years needed to cover costs (Show work):*Bold items indicate what you calculated in a previous step:*

Step 1. watts generated ÷ (length × width) = watts per square meter

Step 2. 790 watts ÷ **watts per square meter** = total square meters needed

Step 3. Cost per square meter * × **total square meters needed** = total upfront costs

Step 4. 6 hr. per day × 0.790 kWh/hour × cost of electricity per kWh*= $ saved per day

Step 5. (**total upfront costs** ÷ **$ saved per day**) ÷ 365 days/yr. = total yr. needed to cover costs

*These items can be looked up at the following websites:

https://askingcenter.com/cost-of-solar-panels-per-square-foot/

https://www.electricchoice.com/electricity-prices-by-state/

Assignment Checklist:

1. Did you answer all the questions?
2. Did you show your work?