# Efficiency of a Motor and a Generator

**Object:**     The purpose of this laboratory activity is to determine the efficiency of an electric motor and the efficiency of an electric generator.

**Apparatus:**  Electric Motor/Generator apparatus, photo-gate, power amplifier, various masses, Voltage Sensor, computer, PASCO Interface, and Data Studio Software

## FOREWORD

### Motor Efficiency

The efficiency of a motor is the ratio of the mechanical work done by the motor ($W_{out}$) to the electrical energy input to the motor ($E_{input}$):

**(1)**                                    $\text{efficiency}_{motor} \ = \ e_{motor} \ = \ W_{out}/E_{input}$

In this laboratory activity, the motor does work by lifting a mass m a distance h (see **Figure 1**).  Hence, the mechanical work done by the motor ($W_{out}$) is just the change in gravitational potential energy (mgh) of the mass m.

**(2)**          Mechanical work done by the motor $= W_{out} \ = \ \Delta(\text{gravitational potential energy}) \ = \ mgh$

The electrical energy input to the motor ($E_{input}$) is the electrical power supplied to the motor ($P = VI$) multiplied by the time ($\Delta t$) it takes the motor to lift the mass m.

**(3)**                              Electrical energy input to the motor $= E_{input} \ = \ P\Delta t \ = \ VI\Delta t$

The software will measure V and I (from the signal generator) one hundred times per second, use the calculator to determine VI and then plot $P_{in}$ ($P_{in} = VI$) vs. t.  The area under this curve (found by integration) is then the electrical energy into the motor.

### Generator Efficiency

The efficiency of a generator is the ratio of the electrical energy produced by the generator  ($E_{out}$) to the mechanical work done on the generator ($W_{input}$).

**(4)**                                    $\text{efficiency}_{generator} \ = \ e_{generator} \ = \ E_{out}/W_{input}$

Mechanical work is done on the generator  ($W_{input}$) by the mass m falling the same distance h it was lifted by the motor, hence:

**(5)**          Mechanical work done on the generator $= W_{input} \ = \ \Delta(\text{gravitational potential energy}) \ = \ mgh$

The electrical energy produced by the generator ($E_{out}$) is the electrical power produced by the generator ($P = V^2/R$) multiplied by the time of fall:

**(6)**                              Electrical energy produced $= E_{out} \ = \ P\Delta t \ = \ (V^2/R)\Delta t$ by the generator

The software will measure V (the voltage drop across the resistor due to the current from the generator), use the calculator to determine $V^2/R$ and then plot $P_{out}$ ($P_{out} = V^2/R$) vs. t. The area under this curve (found by integration) is the electrical energy output of the generator.

## PROCEDURE

The figure below, shows the experimental arrangement for this lab activity.
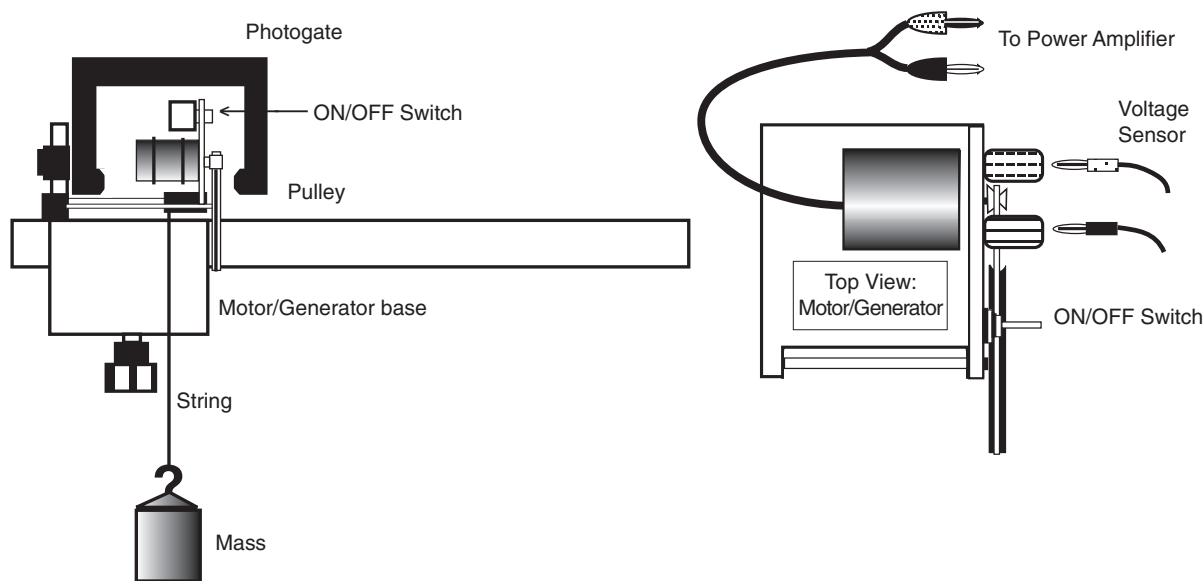


**Figure 1. Front and top view of the motor/generator apparatus.**

## Motor Efficiency

The motor we wish to determine the efficiency of is used to lift the mass m a distance h. The photogate provides the computer with the number of times the light beam is interrupted by a pulley spoke. You tell the computer the linear distance the string travels from one light beam interruption to the next and the computer will calculate the distance h the mass m moves. The Data Studio program displays the distance, and calculates the gravitational potential energy gained by the mass m. At the same time, the Data Studio program measures the voltage and output current drawn from the Power Amplifier by the motor while it lifts the mass and uses them to plot $P_{in}$ vs. t. The area under this curve (found by integration) is the electrical energy input to the motor ($VI\Delta t$).

## Generator Efficiency

The motor is turned off and the mass m is allowed to fall slowly back to the floor, thus generating a voltage that is supplied to a 10 ohm resistor and monitored by a voltage sensor. The program allows you to calculate the power output of the generator ($V^2/R$) and plot this as a function of time. The area under this curve (found by integration) is the electrical energy output of the generator ($V^2/R$) $\Delta t$.

## Part I.  Initial Equipment and Software Set-up

1. Start Data Studio, and select *Create Experiment.*

2. Connect the Power Amplifier to the computer via an analog port on the PASCO interface.  Plug the Power Amplifier into an AC outlet, and turn the power amplifier on.  Supply power to the motor by connecting the power amplifier to the motor.

3. Inform the software which analog port you plugged the Power Amplifier into by selecting the Power Amplifier icon and dragging it to the appropriate analog port.

4. A signal generator box should appear.  Change the wave pattern from the default *Sine Wave* to a *DC signal.*  Adjust the amplitude of the signal to 6.0 volts and select the **auto** switch.  In this mode, any time the motor is switched on and the start button on the control panel is pushed, power is supplied to the motor.  When the stop button on the control panel is pushed, no power is supplied to the motor.  Later, if your motor won't lift the mass selected, you may have to increase the amplitude of the signal to 7 or 8 volts. The software will monitor the voltage and current output of the signal generator.  We are interested in both.

5. Connect a voltage sensor across the 10Ω resistor, and connect it to the computer via an analog port on the PASCO interface.

6. Inform the software which analog port you plugged the voltage sensor into by selecting the voltage sensor icon and dragging it to the appropriate analog port.

7. Connect the photo-gate to the computer via a digital port on the PASCO interface.

8. Inform the software which digital port you plugged the photo-gate into by selecting the **smart pulley** icon and dragging it to the appropriate analog port.

9. Double click on the smart pulley icon and under measurement select position in m and deselect all other measurements.  Under constants select spoke arc length.  You will notice that the default is 0.015 m.  The circumference of the groove of the pulley is 0.15 m and the pulley has 10 spokes, so every time the light is interrupter (when the string is in the pulley groove) the string has wound 0.015 m onto or off of the pulley.   In our present experimental setup, the string is wound onto the axle rather than the pulley.  Since the axle has a circumference of 0.02 m and there are 10 spokes, every time the light is interrupted 0.002 m of string has wound onto or off of the axle.  For this reason, change the default 0.015 m to 0.002 m and then click **OK**.

10. Presently our experimental set up allows us to monitor the distance the mass m moves, the current and voltage the signal generator supplies to the motor and the voltage (provided by the generator) across the 10Ω resistor.  Using this information we need to calculate the work which we get out of the motor ($W_{out} = mgh$) which is also the work that is put into the generator ($W_{input} = mgh$); the electrical power delivered to the motor $P_{in} = VI$; and the power output of the generator $P_{out} = V^2/R$.  Let's agree to do the calculations in this order $W_{out}$, $P_{in}$ and then $P_{out}$.

11. Select the calculator in order to proceed with the calculations.  Replace the y with the name of the first calculation ($W_{out}$), on the right side of the equal sign write the equation needed to calculate this quantity (m*g*h)  then click the green check.  The software will ask you to identify the variables.  Inform the software that m is a constant and provide the value in kg, that g is a constant and provide the value in

m/s$^2$ and that h is a data measurement and select the appropriate data measurement (position in m). Select properties, label the y variable properly and provide its units. Click the green check.

12. Repeat the above process to calculate $P_{in}$ and $P_{out}$. You will need to select **New** calculation before starting each of these calculations.

13. Next we need a graph of $W_{out}$ vs. t, $P_{in}$ vs. t and $P_{out}$ vs. t. The $W_{out}$ vs. t plot may be created by dragging the graph icon to the $W_{out}$ calculation. The $P_{in}$ vs. t plot may be added by dragging the $P_{in}$ calculation icon onto the present graph. Before adding the $P_{out}$ vs. t plot, we need to ungroup the plots. If we don't do this, the $P_{in}$ and $P_{out}$ plots will be superimposed since the y-variables have the same units. To do this double click somewhere within the body of the actual graph, or click on the **Graph Settings** button located on the graph toolbar to open the Graph Settings window. Select the layout tab, and under Group Measurements select the *Do Not Group* option. Select **OK.**

## Part II.  Collection of Data

1. Start with the motor switch in the **off** position.
2. Click the **Start** button, and after two or 3 seconds, flip the motor switch to the **on** position. At this time the motor should start turning, hence winding the string on the axle and lifting the mass m. If the motor won't lift the mass, you need to decrease the mass or increase the voltage of the motor. Note that you must keep enough mass to drive the generator (i.e. fall and turn the generator). When the mass is close to the top, turn the motor **off** and momentarily catch the mass. While holding the mass, unplug the photo-gate, and then release the mass so that it may fall and generate electricity. About 2 seconds after the mass has fallen to the end of the string, click the **stop** button.
3. Click the **autoscale** button located on the graph tool bar and maximize the graph to fill the screen. You now have your data.

## Part III.  Data Analysis

1. Click on the $W_{out}$ vs. t plot, select the statistics package and request the maximum value. This will be the work output for the motor and the energy input for the generator.

2. Click on the $P_{in}$ vs. t plot, select the statistics package and request the area under the curve. This will be the electrical energy input into the motor ($E_{in} = P_{in}t = VIt$).

3. Click on the $P_{out}$ vs. t plot, select the statistics package and select the area under the curve. [$E_{out} = P_{out}t = (V^2/R)t$)].

4. Print your plots and using the information on them complete the Data and calculation sheet to determine the efficiency of the motor and generator.

## DATA AND CALCULATION SUMMARY

**Motor:**

Voltage supplied to the motor = V =               _____ Volts

Mass lifted by the motor = m =               _____ kg

Electrical energy input to the motor = $E_{input}$ =               _____ Joules

Mechanical work done by the motor = $W_{out}$ =               _____ Joules

Efficiency of the motor = $e_{motor}$ =               _____

**Generator:**

Mechanical work done on the generator = $W_{input}$ =     _____ Joules

Electrical energy produced by the generator = $E_{out}$ = _____ Joules

Efficiency of the generator $e_{generator}$ =               _____