  Graphical Analysis 27

Electrical Energy

In this experiment, you will study a small, inexpensive electric motor used as a crude elevator. You will measure the current through, and potential difference (voltage) across, a motor as it lifts a small mass. If you know the current and voltage, you can calculate another electrical quantity—power. The power used by an electrical device can be calculated from

power = current × potential difference

The unit of power is the watt (W). An electrical device that consumes 1 W converts one joule of energy to another form every second (1 J/s). If the power provided to a device is constant over time, you can multiply the power by the time and get the energy. If the power provided to a device changes during the experiment, the electrical energy can be determined by finding the area (integral) under a power vs. time graph.

You will use this approach to determine the electrical energy used by the motor and compare it to the change in gravitational potential energy of the mass. The gravitational potential energy gained by an object can be calculated if you know the mass and the distance it is lifted. By comparing the electrical energy supplied to the motor with the gain in potential energy of the mass you can calculate the efficiency of the motor as a machine used for lifting.

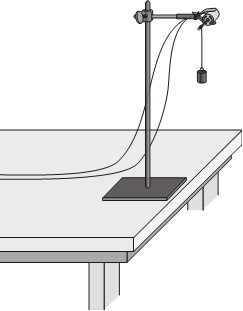


Figure 1

objectives

* Measure the power and electrical energy used by an electric motor.
* Determine the gain in potential energy of a mass lifted by the motor.
* Calculate the efficiency of the motor.
* Study the efficiency of the electric motor under different conditions.

MATERIALS

Chromebook, computer, or mobile device

Graphical Analysis 4 app

Go Direct Current

Go Direct Voltage

Extech Digital DC Power Supply

ring stand

small, wooden dowel rod

connecting wires with clips

electric motor

mass set

string

utility clamp

SEt up and PRELIMINARY QUESTIONS

1. Set up the motor apparatus as shown in Figure 1. Attach an axle on your motor where the string can be wound as the mass is lifted. Allow room for the mass to be lifted at least 0.5 m; a greater height is better. Make a loop at the end of the string for connecting the mass.
2. Connect the circuit as shown in Figure 2. Orient the positive (red) lead of the voltage probe and the red lead from the current probe toward the + terminal of the power supply.

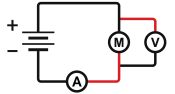


Figure 2

1. Launch Graphical Analysis. Connect the current probe and the voltage probe to your Chromebook, computer, or mobile device.
2. Zero both probes with no current flowing and with no voltage applied (power supply off).
   1. With no current flowing and with no voltage applied, wait for the readings to stabilize.
   2. Click or tap the Current meter and choose Zero.
   3. Click or tap the Voltage meter and choose Zero. The readings for both sensors should be close to zero.
3. Set the voltage control on your power supply to 0 V. Turn on the power supply and gradually increase the voltage setting. Watch the motor to see when it starts to turn slowly. The current and voltage readings are displayed on the screen. Control the voltage so that the motor turns and lifts the mass slowly. Set the control back to 0 V when the mass reaches the top.
4. Explain the energy changes that take place as the mass is lifted.
5. Without making any measurements, make a guess of what you would expect for the efficiency of this electric motor; that is, guess the fraction of the electrical energy consumed by the motor that goes into lifting the mass.

PROCEDURE

1. Check the voltage rating of your motor. This is the maximum voltage you should use. If you are not sure of the rating, ask your instructor. Record the voltage rating in the data table.
2. Place a 10 g mass at the end of the string as the load to be lifted. Note the starting position, as the mass must be lifted the same distance each trial. Measure the distance the mass will rise, and record the value in your data table.
3. Now you will gather data of the current through the motor and the voltage across the motor as it lifts the mass.
   1. Set the voltage control on your power supply to 0 V and turn it on.
   2. Click or tap Collect to start data collection.
   3. Gradually increase the voltage setting on the power supply. Watch the motor to see when it starts to turn slowly and lift the mass. Do not exceed 15 V or 1 A, the maximum ratings for the voltage probe and current probe. You have 10 s to make the lift. Note: If this is not enough time, adjust the time interval in Data Collection Settings.
   4. Set the control to 0 V when the mass reaches the top, which must be before data collection ends.
   5. When data collection is complete, a graph of current and voltage vs. time will be displayed.

Examine the graph of voltage and current readings for the complete process of lifting the mass from the starting position all the way to the top. If necessary, repeat this step until you get a good run.

1. The voltage and current data can be used to calculate the electrical power consumed by the motor as it lifted the mass. To do this, first the moment-by-moment power can be calculated from the product of the current data and the voltage data. Then the total energy consumed can be found from the time integral of the power data.

Calculate the electrical power using P = I × V, and store the data in a new column.

* 1. Click or tap View, , and select Graph and Table.
  2. In the Current column header in the table, click or tap More Options, . Choose Add Calculated Column.
  3. Enter Power as the Name and W as the Units.
  4. Click or tap Insert Expression and choose XY as the expression.
  5. Select Potential as Column Y and Current as Column X. Click or tap Apply.
  6. Click or tap View, , and select 1 Graph.
  7. To display the graph of power vs. time, click or tap the y-axis label, select only Power, and dismiss the box.

1. The energy used is the product of the rate at which it was used and the time over which it was used. To account for the variations in the rate, the energy is calculated from the integral of the power vs. time data. For data taken in discrete time steps, this is equivalent to the sum of the power at each moment times the length of each time step. Fortunately, this sum can be calculated easily.
   1. On the power vs. time graph, select the region when the mass was being lifted.
   2. Click or tap Graph Tools, , and choose View Integral. The integral value for the power data will be displayed on the screen. The area, or integral, of the power data value has units of W•s, or J.
   3. Record the value of the power integral as Electrical Energy Used in the data table.
2. Increase the load by 10 g and repeat Steps 3–5. As before, collect voltage and current data for the entire lift. Note the mass used in each run in the data table.
3. Repeat Step 6 five more times, or until the motor will not lift the load. Lift the mass the same distance each time.

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| Data Table   |  |  | | --- | --- | | Distance mass was lifted (m) |  | | Voltage rating of motor (V) |  |  |  |  |  |  |  | | --- | --- | --- | --- | --- | | Run | Load lifted  (g) | Electrical energy used  (J) | Mechanical energy output  (J) | Efficiency  (%) | | 1 |  |  |  |  | | 2 |  |  |  |  | | 3 |  |  |  |  | | 4 |  |  |  |  | | 5 |  |  |  |  | | 6 |  |  |  |  | | 7 |  |  |  |  | |

ANALYSIS

1. For each experimental run, calculate the increase in gravitational potential energy of the mass in joules. The increase in gravitational potential energy is equal to the mechanical energy output of the motor. Record the values in the data table.
2. For each run, calculate the efficiency of the motor; that is, what percentage of the electrical energy into the motor was converted to gravitational potential energy? Record your answer in the data table.
3. For which load was the motor most efficient?
4. What happened to the remainder of the electrical energy that went to the motor?
5. How does the typical efficiency of your motor compare to the fraction of electrical energy converted to work that you guessed in the Preliminary Questions?

EXTENSIONS

1. Investigate the efficiency of the motor at different speeds using the same load.
2. Try other motors and see if you can find more efficient ones.
3. Use a Temperature Probe to monitor the temperature change of the motor.
4. Show that the following units are equivalent: 1V × 1A = 1 J/s.
5. Can you use your motor as a generator? Raise the mass using the motor and hold it at the top by hand. Turn off and remove the power supply. Connect a 10 Ω resistor between the leads on the power supply. Take current and voltage data of the power generated by the falling mass as it turns the motor. You may need to add more mass. Compare the power measured by the interface to the change in gravitational potential energy of the falling mass.