

Name: _____
Partner: _____

Use a pencil!
Motor #: _____

Purpose: In class, we often model a load as a resistor. However, real loads are often a little different. Today, we're going to look at a small (Lego) DC motor to see how it's electrical properties depend on torque and voltage. The "resistance" of a motor changes as its mechanical load changes.

Motor Summary: A motor converts electrical power ($P_{in} = \Delta V \cdot I$) into mechanical power ($P_{out} = \omega \tau$). Because some energy is wasted in the process, the efficiency is $\eta = \frac{P_{out}}{P_{in}}$. In this

lab, we'll generate torque τ by hanging small masses from a wheel of radius R that's attached to the motor. Then, we'll apply voltage to activate the motor, and raise the mass. If the motor is spinning with constant ω , then the torque is equal to mgR . The wheel has 20 regularly spaced holes in it; we'll shine an LED through these holes onto a sensor and use LabVIEW to monitor the flicker rate seen by the sensor to determine ω . LabVIEW will return a value only when it is convinced that ω is constant. Also, LabVIEW will monitor the voltages V_o and V_M seen in the circuit on the next page. You can use the 15Ω "shunt" resistor to determine I_m . For each "successful" trial, LabVIEW will record the following data for you:

$$\tau, \omega, P_{in}, P_{out}, \eta, I_m, V_m, \text{ and } R_m.$$

Procedure:

1. First, measure the basic constants and record them here →

When measuring the diameter of the wheel, measure the diameter of the groove *where the string sits*, not the outer diameter of the wheel itself.

Basic Constants:
$R_{\text{motor, no load}}$: _____ Ω
$R_{\text{shunt, actual}}$: _____ Ω
R_{wheel} : _____ mm

2. Build the circuit (on the next page). You'll notice that there are two different models of op-amp. The TLV-272 is a good quality signal amplifier. It's needed because LabVIEW can't create outputs higher than 5 V. The L272AM is then being used to directly deliver power to the motor.

3. Download the LabVIEW program from the ECA homepage. It's in a zip file that you *must unzip to a real folder* before using. Once unzipped, double click on "!2024Motors.vi" to open it. Then, to actually run this program, click the white arrow near the upper left corner. Enter filename, and values for the disc diameter and the small resistor. The "Rising mass" might change for each run.

4. Perform the experiments. Use masking tape to affix the plastic motor holder to the edge of a table so the string can hang freely below the surface. For each combination of mass (~0, 10, 20, ... 80 g) and voltage (3, 4, 5, ... 8 V) perform at least one good trial (for a total of 54 good trials!). Don't let the weights crash into the motor holder... after each trial, re-extend the string to it's full length. If the string falls off the track, **carefully** spin the wheel clockwise by hand until it is free.

A good trial will show the actual motor voltage in green onscreen. "Fair" trials will show yellow. A trial might fail for 2 reasons: the speed was never consistent, or the measured motor voltage was too different from the requested value. You won't know for sure that "yellow" data is OK until you look at it in Excel. A common problem is if your 220 k Ω resistors don't all match. When you build the 110 k Ω from two of them, use the two "extreme" values, saving the "medium" value for the 220 k Ω resistor. If you consistently have failed trials, move the "quality" slider to the left.

5. Analyze the circuit (i.e., on paper), and answer these questions →.

For the motor voltage, write the expected *formula* for V_m in terms of LabVIEW output A00. For the motor current, write the expected formula in terms of V_0 , V_m , and R_{shunt} .

Circuit Analysis:

npn $V_{c, dark}$: _____ $\frac{V}{V}$

npn $V_{c, bright}$: _____ $\frac{V}{V}$

$V_m =$ _____ .

$I_m =$ _____ .

6. Check and sort the data. Data is recorded automatically into the file *YourChosenName.csv* that will open in Excel. This file will be created in the same folder where *you* chose to unzip the LabVIEW program. Look over the “voltage” column, which is V_m . *Sort* your data into blocks of constant voltage (i.e., list the 3 V data first, then 4 V, etc.). You’ll notice that for some “high” loads, the voltage didn’t match the “requested” voltage, because the L272AM op-amp wasn’t powerful enough to provide the necessary current. **Delete any data for which the actual voltage was about 0.05 V or more away from the intended voltage.** It’s not that this data is necessarily bad, it’s just too hard to check whether it’s bad. Now, make separate plots of ω vs τ for each voltage. Each plot should be pretty linear. Delete any data points that aren’t on the line... they represent trials where the speed wasn’t very constant.

7. Analyze the data. Here, the impedance of the motor is defined as (V_m / I_m). Note that the units for some of the data (torque, Power, current) involve “milli-”. You’ll want to make a lot of Excel plots to answer these questions. Don’t worry about uncertainties.

- I_m depends on τ , but not on V_m . Plot it. Find the best-fit slope “ m ” and intercept “ b ” of the straight line using *all* your validated data.
- ω is co-linear with torque *and* velocity (i.e., $\omega = A\tau + BV_m$). You should start by plotting ω vs τ for each voltage as multiple series *on the same plot*. Have a legend for Voltage. You’ll see right away that the line for each voltage has the same slope A , but they have different intercepts. Use all your data in “Solver” to find A and B .

All remaining questions should be answered by mere symbolic manipulation of the prior two results. So, answers will depend only on the values of m , b , A , and B .

- For each specific voltage, P_{out} vs. τ is a beautiful parabola for each specific voltage V_{motor} . Find the symbolic formula for the parabola, then plot and *use* it to determine the torque that results in the *maximum power for each voltage*, called the “design” torque. Determine τ_{design} as a function of V_m . Look at your plot to see if you got it right! You should expect to have no intercept for your parabola equation.
- For each voltage, there exists a maximum torque τ_{limit} for which the motor can even turn (i.e., when P_{out} is zero). How is τ_{limit} related to τ_{design} ?
- Similarly, P_{design} is a quadratic function of V_m , with no intercept. Find it.
- Perhaps the main idea of this lab concerns the impedance of the motor, which depends on both voltage and torque. However, because of the unusual form of the result, it’s easier to write the reciprocal of the resistance, called the “admittance” of the motor (i.e., $Y_m = 1 / R_m$). Plot Y_m vs. τ for each V. Write an expression for Y_m , assuming that Y_m is of the form shown below.

In your Excel document, keep only 5 plots: [I vs τ] (for all V), [ω vs. τ] with multiple series, [P_{out} vs τ] with multiple series, [Y vs τ] with multiple series, and [η vs τ] with multiple series. For all plots, dots represent actual measurements, but lines represent calculations based on only the first two curve fits from a) and b) above. So, for example, **DO NOT** fit your efficiency data directly!

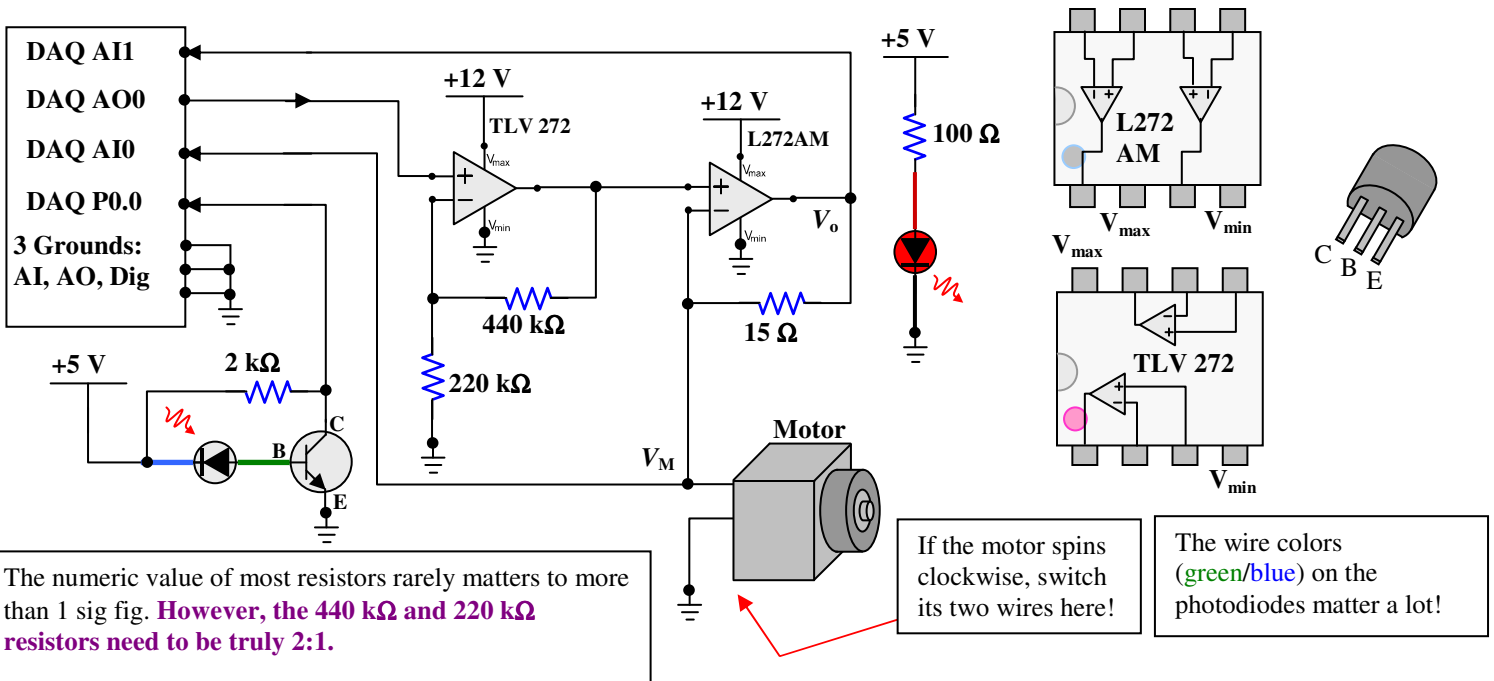
Submit the following results. Also, submit your well-organized and annotated Excel file that includes all your data and calculations to my inbox: \\files\Inbox\Physics\Pogo\ECA\MotorLab

Data Analysis Results. Most numbers require units!

- a. $I_m = (\quad) \cdot \tau + (\quad)$
- b. $\omega = (\quad) \cdot \tau + (\quad) \cdot V_m$
- c. $P_{out} = (\quad) \cdot \tau^2 + (\quad) \cdot V_m \cdot \tau$
- d. $\tau_{design} = (\quad) \cdot V_m$
- e. $\tau_{limit} = (\quad) \cdot \tau_{design}$
- f. $P_{design} = (\quad) \cdot V_m^2$
- g. $Y_m = (\quad) \cdot (\tau/V_m) + (\quad) \cdot V_m^{-1}$

Lab Equipment:

- Computer with LabVIEW
- NPN-2222 transistor
- Lego 43362 motor and wires
- plastic motor holder
- TLV 272 op-amp
- weight set (5, 10, 20, 20, 50, 50g)
- PAD-234 circuit box with +5 V and +12 V supplies.
- Resistors: 1 × 15 Ω, 1 × 100 Ω, 1 × 10 kΩ, 4 × 220 kΩ (but you only need 3!)
- 5 long wires and a variety of short wires.
- USB-6008 DAQ
- Red LED with long wires
- IR photodiode with long wires
- plastic disc with string
- L272AM op-amp
- Tape, rulers



The numeric value of most resistors rarely matters to more than 1 sig fig. **However, the 440 kΩ and 220 kΩ resistors need to be truly 2:1.**

If the motor spins clockwise, switch its two wires here!

The wire colors (green/blue) on the photodiodes matter a lot!

If I could, I would prohibit you from even touching the diodes, because you're so careless. So, even though you *may* touch them, you may **NOT EVEN SLIGHTLY** bend these two wires that come out of *either* diode holder. Any bends must be at least 6 inches away from the holders!!

