NAME:____ **Microcontrollers**
DATE: March 1, 2022 **ENGR 3410**
Take Home Exam # 1, Due: Thursday, March 8 **Dr. Slaton**

You are tasked with determining the useful life of a 9V battery. See the included spec sheet from Energizer for their Industrial 9V battery brand. As the chemical reaction inside the battery uses up limited reagents to provide the electrons for the circuit to operate the battery performance will drop. The battery is considered "dead" if its voltage drops to 4.8 Volts. While batteries have a known total amount of charge, in units of amp-hours or milliamp-hours (think about the units!), this total amount may not be available for all discharge currents; again refer to the spec sheet for the Energizer 9V battery. Traditionally, the 9V battery is used in situations with low current draw for long periods of time while the AA, C, & D cell batteries are designed for lower voltage but much higher current draw for a short amount of time. Trade-offs in weight and size must be made to provide a battery pack for a device that requires a given voltage, current draw, and useful operating time before replacement.

A voltage divider circuit, as illustrated in Figure 1 below, literally divides the input voltage, v_{in}, into a smaller output voltage, v_{out}. Our 8-bit (or 10-bit) analog to digital chips can measure voltages from ground, 0V, to 5V so by properly choosing the resistors we should be able to control the current flowing in the circuit and measure a smaller voltage but be able to relate it to the battery's voltage as it drains.

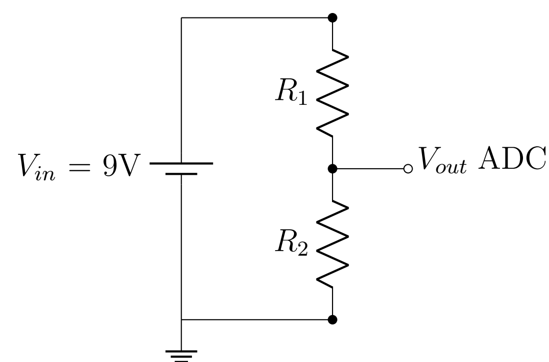

Figure 1: 9V battery (on left) in series with two resistors, R_1 and R_2 (on right). The input voltage (relative to ground) is on the left while the output voltage (relative to ground) is across R_2. **NOTE:** The negative terminal of the battery must also connect to one of the Raspberry Pi's ground pins.

1. The two resistors, R_1 and R_2, form a voltage divider. We can't use the 8-bit (or 10-bit) ADC chip to measure the full voltage so we will measure across R_2. By choosing values for R_1 and R_2 we can relate the voltage we measure to the voltage of the battery. If we pick $R_1 = R_2 = R$ show that $V_{out} = V_{battery}/2$. What should the value of R be to have an initial current of 45 mA? Assuming this is a constant current draw how many <u>hours</u> will it take for the battery to discharge? Hint: Refer to the spec sheet and note that the battery has a capacity of about 400 mAh at a steady current draw of 45mA. You should estimate that the total time to discharge could be almost twice this value so plan your long-term data logging experiment accordingly!

2. Write a Python program (or modify a previous one) to record the voltage, V_{out}, and the time until $V_{battery}$ is equal to 4.8V. You will want to think carefully about how often you need to take data given the Raspberry Pi's limited memory and your estimate for how many hours the program might run. You don't have to stay awake while the experiment runs; you will build a robot to take the data for you.

3. Build a circuit similar to Figure 1 using the 9V battery provided and two resistors, $R_1 = R_2 = 100\Omega$. Use the 1/2-Watt 100Ω resistors in the parts bin not the 1/4-Watt resistors. Why? Hint: Calculate

the power dissipated in the resistors using the initial current. You will want to start recording data very quickly upon building the circuit (or start collecting data before plugging in the battery). **NOTE:** The negative terminal of the battery must also connect to one of the Raspbery Pi's ground pins. Double check the polarity of the battery connector pins before plugging it into the circuit.

4. Once complete make a plot of the battery voltage vs time which is related to the data you took. Properly label the plot axes etc. How long does it take for the 9V battery to discharge to 4.8V in this circuit? Your data should be similar to Figure 2.

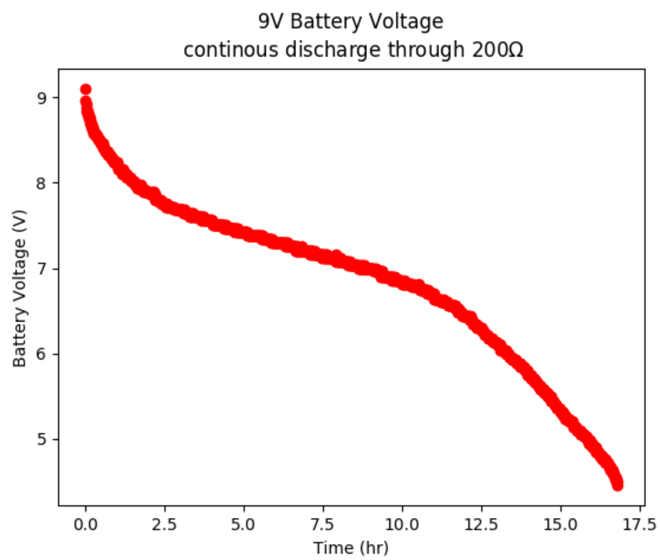

Figure 2: Continuous discharge of a Energizer Industrial 9V battery into a 200Ω resistance.

5. Use the voltage data and the values of the resistors you used to make a plot of the current provided by the battery vs time. Properly label the plot axes etc. The integral of the current vs time is the total charge provided by the battery (ie it's capacity)[1]. You don't have a functional form of $I(t)$ but you can still numerically integrate your data to determine the total charge, Q, provided by the battery. Recall that,

$$Q = \int_{t_{\text{start}}}^{t_{\text{end}}} I(t)\, dt = \sum_{i=0}^{N} I_i\, \Delta t,$$

where I_i are your calculated currents from the measured battery voltage at each time, i is the index value in the array of currents, N is the total number of measurements, and Δt is the difference in time between measurements. Use what you have learned and measured with the above description to calculate the total charge provided by the battery during your experiment. What is the 9V's capacity (in Coulombs and milliAmp-hours) at an initial current draw of 45mA?

6. Write a full lab report including plots, program, analysis, and program flow chart logic as described in the Microcontrollers lab write up template document to be turned in on the due date listed above. Upload your code (data collection and plot generating code), the data file you created, and your report as a pdf to your Exam 1 Github folder.

[1]Current (Coulombs/sec) × time (sec) = Charge (Coulombs)