CG1111 Engineering Principles and Practice I

DC Circuit Principles III – Thevenin Equivalent

Week 4's F2F Studio

Sub-group 'a': Come during Studio 1 timeslot (**Monday/Tuesday**)

Sub-group 'b': Come during Studio 2 timeslot (**Wednesday/Thursday**)

Time	Duration (mins)	Activity
0:00	20	Briefing on Activity #1 & Activity #2
0:20	45	Activity #1: (this part is not graded, but you should include it in your graded report for continuity) An experiment to understand the impact of internal resistances in batteries, as well as to estimate their values in the two given 'D' size batteries
1:05	85	Activity #2: (graded – only this activity is graded) An experiment to estimate the internal resistance of a power source formed by connecting two cells in parallel
2:30	5	Final discussions and wrap-up

Introduction:

- We have all experienced the use of batteries in our daily lives. You might have noticed that a battery warms up significantly when a lot of power is drawn from it (e.g., the batteries in a fast toy car, the laptop's battery when you do some serious gaming, etc.). This tells us that a battery has energy loss in the form of heat when used, and this loss somewhat occurs at a faster rate when the power drawn by the external load increases.
- So, how do we model this loss? If we model a battery as a pure voltage source, we cannot account for the energy loss in the battery. In electrical circuit principles, a loss occurs when current passes through a resistive element. Hence, we typically model a battery as a voltage source in series with a resistance, which we call the "internal resistance" of the battery.
- If you compare the battery's model with the Thevenin equivalent circuit that you have learnt in the self-learning materials, what do you observe?
- Looking at the model, how do you think a battery's terminal voltage would change as the current drawn increases?
- Should a good battery have high or low internal resistance?
- In this studio, you will perform hands-on activities and see for yourself the effect of internal resistance in batteries, as you seek the answers to the above.
- You will also get to practice the application of Ohm's Law and Kirchhoff's Laws, as well as the derivation of the Thevenin equivalent for a simple electrical circuit.

Activity #1: An experiment to understand the impact of internal resistances in batteries, as well as to estimate their values in the two given 'D' size batteries (45 mins)

Objectives:

- Understand the impact of internal resistances in batteries
- Able to estimate the internal resistances of the two batteries given
- Practise the application of ***Ohm's Law*** and ***Kirchhoff's Laws***

Equipment and Materials:

- Breadboard and connecting wires
- Two 'D' size batteries (one Energizer and one Duracell), and two battery cases
- Digital multimeter
- Power resistors: 4.7 Ω, 5.6 Ω, 8.2 Ω, 10 Ω (5% tolerance, 0.5 W rated)

Procedure:

1. The power resistors used in this studio has 0.5 W rating. Take a moment to convince yourself why we cannot use the usual 0.25 W resistors with the 1.5 V batteries.

2. Just like the smaller 0.25 W resistors you have seen in previous studios, these 0.5 W resistors also have 5% tolerance. Using the multimeter, measure and record the resistance values of the four power resistors in Table I.

3. Use the multimeter to measure the open-circuit voltage V_{open} of each of the two batteries, and note them down in Table I. If any of the batteries has V_{open} < 1.45 V, please request to change the battery.

Table I

		Duracell		Energizer	
Nominal resistance value (Ω)	Measured resistance value R (Ω)	Voltage V_R (V)	Calculated Current I_R (A)	Voltage V_R (V)	Calculated Current I_R (A)
∞ (open circuit)			0		0
10 Ω					
8.2 Ω					
5.6 Ω					
4.7 Ω					

4. Using the breadboard, construct the circuit shown in Figure 1 using the Duracell. You shall vary the resistance R using the four power resistors given, one at a time, while taking note of the voltage across R using the digital multimeter. Tabulate your readings using the format given in Table I.

Note:

1) **Disconnect the battery once you have completed each measurement** to avoid draining the battery as this may affect your experimental results.
2) The voltage shown on the multimeter may keep dropping once the circuit is closed. **Do not wait for it to become stable.** Instead, take the reading about 2-3 seconds after closing the circuit.
3) To measure the voltage across the resistance *R*, **clip your multimeter probes to the resistors' legs**. If you take the voltage reading directly across the battery inside the battery case, your reading would be different (why?).

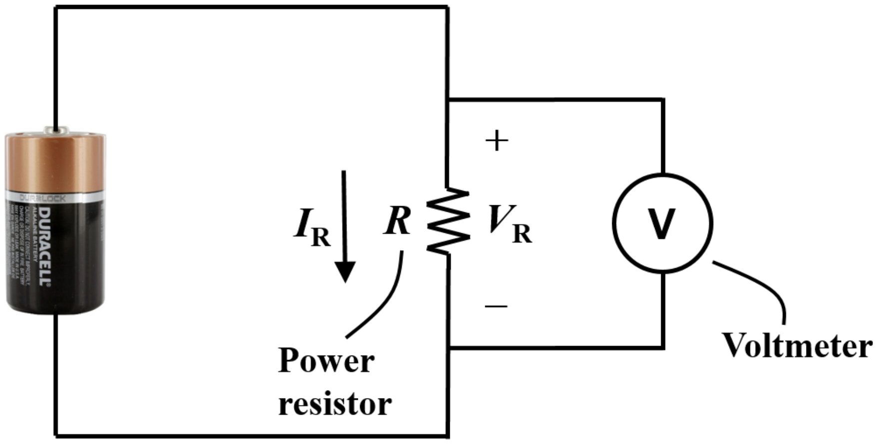

Figure 1: Circuit for determining the internal resistance of the battery.

5. Using Ohm's Law, calculate the current I_R passing through each of the power resistors and include them in Table I. **Do not use your multimeter to measure the current! (Why?)**

6. Repeat the above experiment (i.e., Steps 2 to 5) for the Energizer.

7. A practical voltage source, such as a battery, can be ***modelled*** as a series connection of an ideal voltage source of voltage V_{open} and the practical source's internal resistance R_{int}. (Note that this is a Thevenin equivalent circuit!) Using Kirchhoff's Voltage Law and Ohm's Law, derive an expression for the voltage V_R in terms of V_{open}, I_R, and R_{int}.

8. From the data you have collected in Table I, plot in Microsoft Excel (using the "Scatter Chart" option) the voltage V_R against the current I_R for <u>each</u> battery (i.e., two plots in total) by fitting an appropriate line through the data points (should it be linear or non-linear?). Note that V_{open} also gives you one data point. With the help of the equation you have derived in Step 7, decide what value you should set as the y-axis' intercept by selecting the option "Set Intercept". Also select the option "Display Equation on chart". Compare this equation with the equation you have derived in Step 7, and estimate the internal resistance R_{int} of each battery from the fitted line's equation. Copy and paste the graphs into your report.

9. From your observations above, what happens to a battery's terminal voltage as the current drawn from the battery increases? Can you relate this behaviour to the battery discharge graphs you have seen in earlier studio?

10. Should a good battery have high or low internal resistance? Why? Do you now understand why a higher discharge current leads to lower battery discharge capacity left for the external load?

11. **<u>Suppose</u>** you shorted the terminals of the Duracell. **(Caution: please don't physically short the battery.)** What would be the theoretical current? Estimate the instantaneous power dissipation in the battery under this condition.

<u>Activity #2: An experiment to estimate the internal resistance of a power source formed by connecting two cells in parallel (85 mins)</u>

Note: This activity will be assessed. Students are required to submit <u>individual</u> lab reports (upload in PDF format to submission folder) before the studio ends.

Objectives:

- Able to estimate the internal resistance of a power source formed by two cells in parallel
- Able to derive the ***Thevenin equivalent circuit*** for a simple electrical circuit comprising two Thevenin equivalent circuits connected in parallel
- Understand the drawbacks of connecting ***non-matching*** batteries in parallel

Equipment:

- Breadboard and connecting wires
- Two 'D' size batteries (one Duracell and one Energizer), and battery cases
- Digital multimeter
- Power resistors: 4.7 Ω, 5.6 Ω, 8.2 Ω, 10 Ω (5% tolerance, 0.5 W rating)

Procedure:

1. Connect the Duracell and the Energizer batteries in parallel using the breadboard (i.e., connect the "+" terminal of the Duracell to the "+" terminal of the Energizer, and do the same for their "–" terminals). Measure the open-circuit voltage V_{open} of this combined power source. **(Caution: If the batteries feel warm/hot, disconnect them immediately and recheck the batteries' polarities.)**

2. Using the breadboard, construct the circuit shown in Figure 2. Similar to Activity #1, you shall vary the resistance *R* using the 4.7 Ω, 5.6 Ω, 8.2 Ω, and 10 Ω power resistors, and take note of the voltage across each *R*. Tabulate your readings using the format given in Table II. **(Note: Again, remember to disconnect the batteries once you have completed each measurement to avoid draining the batteries as this may affect your experimental results.)**

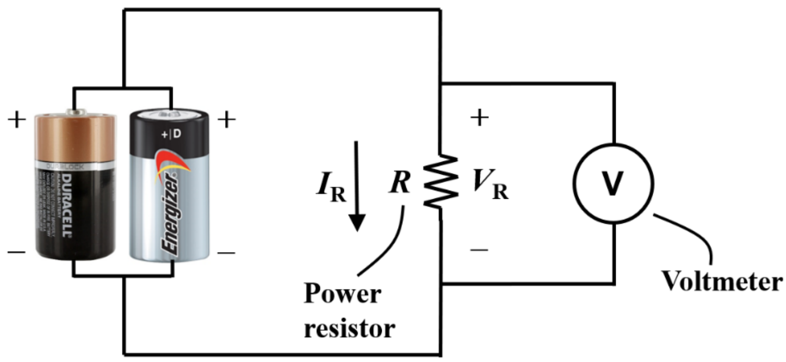

Figure 2: Circuit with power source formed by two parallel batteries.

Table II

		Parallel Batteries	
Nominal resistance value (Ω)	Measured resistance value R (Ω)	Voltage V_R (V)	Current I_R (A)
∞ (open circuit)			0
10 Ω			
8.2 Ω			
5.6 Ω			
4.7 Ω			

3. Similarly, use Ohm's Law to calculate the corresponding current I_R passing through each of the power resistors when it is used, and enter the values in Table II.

4. From the data you have collected in Table II, plot in Microsoft Excel the voltage V_R against the current I_R for the combined parallel batteries. Remember to "Set Intercept" and "Display Equation on chart". Copy and paste the graph into your report, and write down the equation estimated by Microsoft Excel for your fitted line. Also write down your estimated internal resistance R_{int} of the combined power source.

5. Next, construct the circuit shown in Figure 3. The circuit consists of two batteries connected in parallel, with a multimeter serving as an ammeter connected as shown. Take note of the polarity of the ammeter's terminals so that you are aware of the current's direction you are reading. A positive reading means that current is flowing into the red clip of the ammeter and exiting from the black clip. A negative reading means that the reverse is happening. **(Caution: Be careful with the batteries' polarities. If you connect the batteries in series (i.e., connecting the "+" terminal of one battery to the "–" terminal of the other battery, the current will be high and will blow the fuse of the ammeter.)**

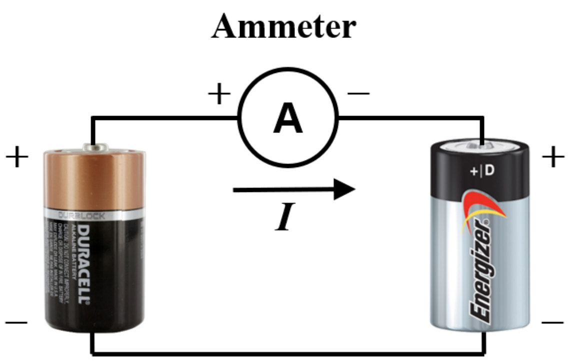

Figure 3: Circuit for measuring current flow between two batteries connected in parallel.

6. Write down the value of the measured current, I. Explain why there is a current flowing between the two parallel batteries, even though there is no external load.

7. Using the Thevenin equivalent circuits of each of the Duracell and the Energizer batteries, derive the theoretical value of the current, I, via simple circuit analysis (hint: use KVL and Ohm's Law), and compare it with the value you'd obtained from the experiment.

   [Hint: The following circuit diagram in Figure 4 may help you in your circuit analysis. Here, we simply assume the current's direction (**which may or may not be correct**; we will find out at the end). **Note that the labelled polarities of V_{RD} and V_{RE} in the figure actually result from our assumed current's direction. This is because the voltage of a resistor must drop in the direction of the current. You cannot apply Ohm's Law correctly if you label it otherwise!!** Eventually, if you get a negative value for I, it is OK so long as you **clearly indicate** the assumed current's direction in the drawing.]

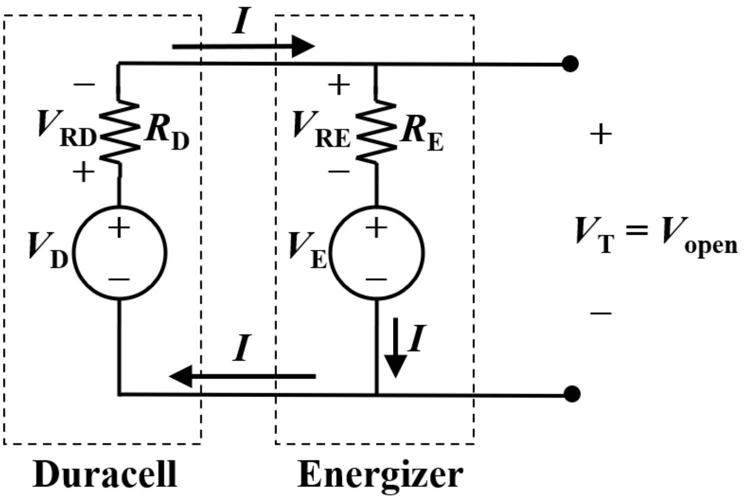

Figure 4: Circuit diagram showing two batteries' equivalent circuits connected in parallel.

8. Continuing from the theoretical analysis in Step 7, derive the theoretical Thevenin equivalent circuit of the combined power source formed by the two parallel batteries. Compare your results with the V_{open} you have obtained in Step 1, and the R_{int} you have obtained in Step 4.

9. Compare the Thevenin resistance of the combined parallel batteries with the original Thevenin resistance of each of the two individual batteries. You should find that the former is smaller than the latter. Name two advantages of having a smaller Thevenin resistance (i.e., internal resistance)?

10. When building a battery pack that consists of parallel branches of cells, what precaution should you take when choosing the cells? (Relate it to what you have observed in Step 6.) Explain what might happen if this precaution is not taken.

END OF STUDIO SESSION