EMF & Internal Resistance of a Battery

Unit: DC Circuits

NGSS Standards/MA Curriculum Frameworks (2016): N/A

AP® Physics 2 Learning Objectives/Essential Knowledge (2024): 11.5.B, 11.5.B.1.iii, 11.5.B.2, 11.5.B.3

Mastery Objective(s): (Students will be able to…)

- Solve problems involving relationships between voltage, current, resistance and power.

Success Criteria:

- Variables are correctly identified and substituted correctly into the correct equation.
- Algebra is correct and rounding to appropriate number of significant figures is reasonable.

Language Objectives:

- Describe the relationships between voltage, current, resistance, and power.

Tier 2 Vocabulary: current, resistance, power

Labs, Activities & Demonstrations:

- batteries and resistors (< 10 Ω) to measure emf in a low-resistance circuit

Notes:

An ideal battery always supplies current at the voltage of the electrochemical cells inside of it. In a real battery, the voltage is a little less when the battery is "under load" (supplying current to a circuit) than when it is tested with no load. This difference is caused by real-world limitations of the chemical and physical processes that occur inside of the battery.

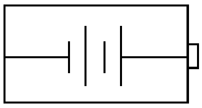
electromotive force (emf): the potential difference (voltage) supplied by a battery without load. This is the stated voltage of the battery. The term "electromotive force" literally means "electron-moving force". EMF is often represented by the variable ε.

voltage: the observed potential difference between two points in a circuit. The voltage of a battery usually means the voltage under load.

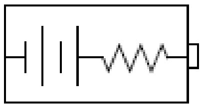
internal resistance (*r*): a model that explains the difference between the emf of a battery and the voltage (potential difference) it can supply as if the drop in voltage were caused by a resistor inside of the battery. In this course, we will use the variable *R* for the resistance of components in a circuit, and *r* for internal resistance.

<u>ideal battery</u>: a battery that has no internal resistance.

To account for internal resistance, we model a battery as if it were a power supply with the ideal voltage, plus a resistor that is physically inside of the battery.



ideal



model

Note that this is a model; the actual situation is more complex, because in addition to the resistivity of the battery's component materials, the difference between the internal voltage and the supplied voltage also depends on factors such as electrolyte conductivity, ion mobility, and electrode surface area.

The following table shows the nominal voltage and internal resistance of common Duracell (coppertop) dry cell batteries of different sizes. These numbers are given by the manufacturer for a new battery at room temperature (25°C):

Size	**AAA**	**AA**	**C**	**D**	**9V**
V_{NL} **(V)**	1.5	1.5	1.5	1.5	9
R_{int} **(mΩ)**	250	120	150	137	1 700

The internal resistance can be used to calculate the maximum current that a battery could theoretically supply. If you were to connect a wire from the positive terminal of a battery to the negative terminal, the only resistance in the circuit should be the battery's internal resistance.

The theoretical maximum current that the battery can supply is therefore the current that would be supplied when the only resistance is the battery's internal resistance, and can be calculated from Ohm's Law:

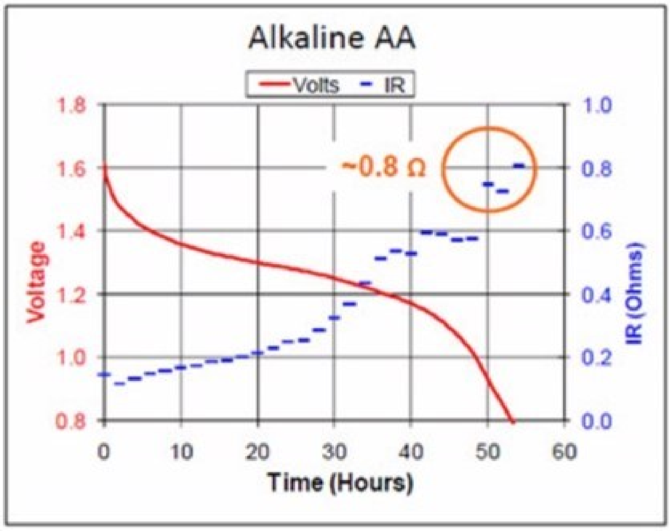
$$I_{\text{max}} = \frac{\Delta V}{r}$$

This concept can be used in circuit analysis by using the following equation:

$$\Delta V_{terminal} = \varepsilon - Ir$$

This equation states that the voltage (potential difference) across the terminals of the battery is the battery's emf minus the potential difference that is "used up" by the internal resistance.

Note also that the factors that affect a battery's internal resistance change as the battery ages. The following graph shows the changes in voltage and internal resistance of an alkaline AA battery as it supplied a current of 50 mA over a duration of about 52 hours.



honors (not AP®)

Internal resistance can be calculated by measuring the voltage with no "load" on the battery (*i.e.,* the voltmeter is connected directly to the battery with nothing else in the circuit) and the voltage with "load" (*i.e.,* the battery is connected to a circuit with measurable resistance):

$$R_{\text{int}} = \left(\frac{\Delta V_{NL}}{\Delta V_{FL}} - 1 \right) R_L$$

where:

R_{int} = internal resistance of battery

ΔV_{FL} = voltage measured with full load (resistor with resistance R_L in circuit)

ΔV_{NL} = voltage measured with no load (voltmeter connected directly to battery)

R_L = resistance of the load (resistor) that is used to experimentally determine the internal resistance of the battery