

Today's agenda:

Potential Changes Around a Circuit.

You must be able to calculate potential changes around a closed loop.

Emf, Terminal Voltage, and Internal Resistance.

You must be able to incorporate all of the above quantities in your circuit calculations.

Electric Power.

You must be able to calculate the electric power dissipated in circuit components, and incorporate electric power in work-energy problems.

Examples.

emf, terminal voltage, and internal resistance

We have been making calculations with voltages from batteries without asking detailed questions about the batteries. Now it's time to look inside the batteries.



<http://www.energizer.com>

We introduce a new term – emf – in this section.

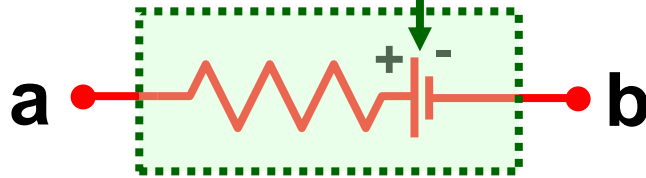
Any device which transforms a form of energy into electric energy is called a “source of emf.”

“emf” is an abbreviation for “electromotive force,” but emf is not a force!

The emf of a source is the voltage it produces when no current is flowing.

The voltage you measure across the terminals of a battery (or any source of emf) is less than the emf because of internal resistance.

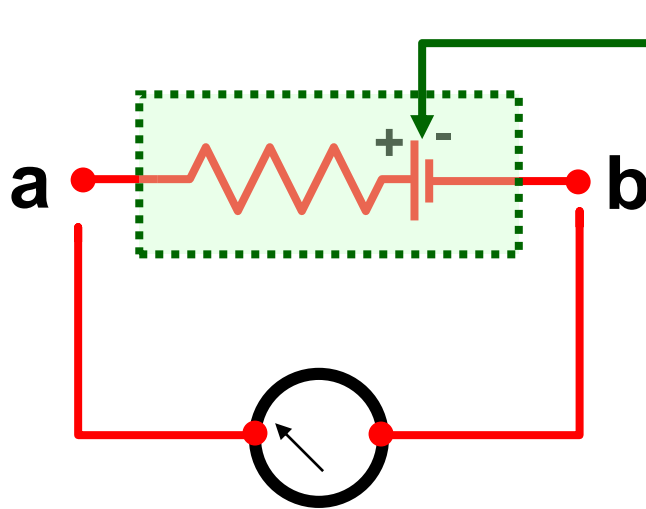
Here's a battery with an emf. All batteries have an "internal resistance:"



emf is the zero-current potential difference

The "battery" is everything inside the green box.

Hook up a voltmeter to measure the emf:

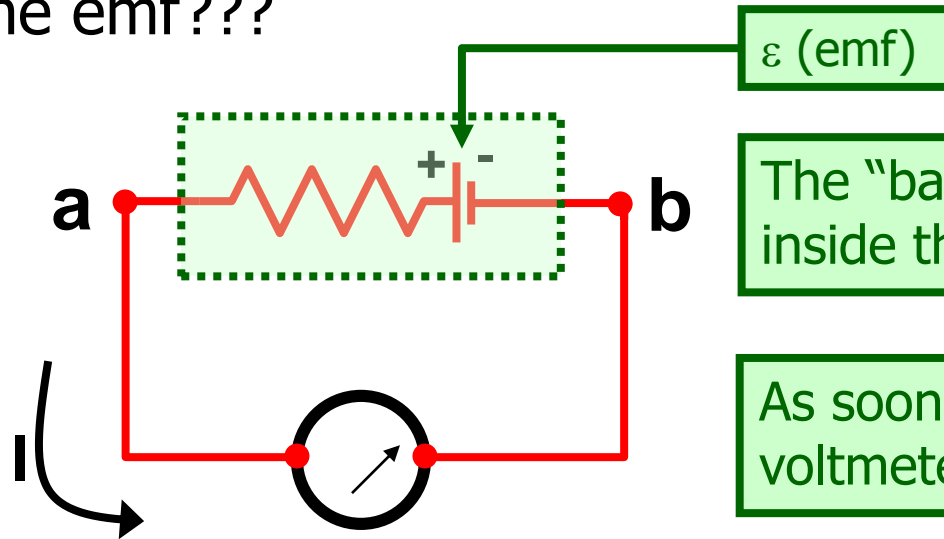


emf

The "battery" is everything inside the green box.

Getting ready to connect the voltmeter (it's not hooked up yet).

Measuring the emf???



The "battery" is everything inside the green box.

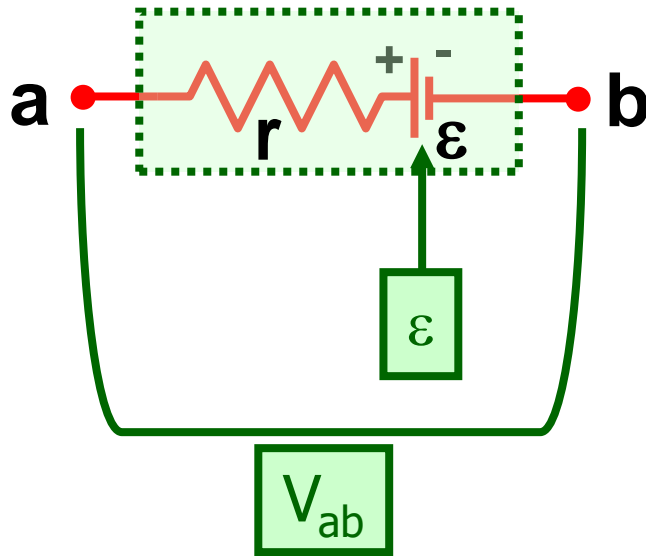
As soon as you connect the voltmeter, current flows.

You can't measure voltage without some (however small) current flowing, so you can't measure emf directly.

You can only measure V_{ab} .

Homework hint: an ideal voltmeter would be able to measure ε . For example, problem 25.32.

We model a battery as producing an emf, ε , and having an internal resistance r :



The "battery" is everything inside the green box.

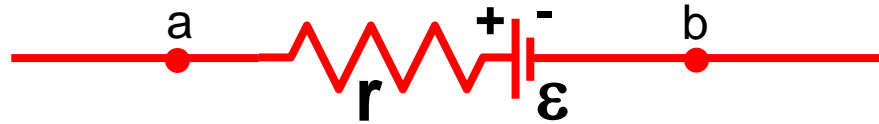
The terminal voltage, V_{ab} , is the voltage you measure across the battery terminals with current flowing. When a current I flows through the battery, V_{ab} is related to the emf ε by

An extinct starting equation.

$$V_{ab} = \varepsilon \pm I r .$$

Not recommended for use by children under 6. Do not continue use if you experience dizziness, shortness of breath, or trouble sleeping. Do not operate heavy machinery after using.

To model a battery, simply include an extra resistor to represent the internal resistance, and label the voltage source* as an emf instead of V (units are still volts):



If the internal resistance is negligible, simply don't include it!

If you are asked to calculate the terminal voltage, it is just $V_{ab} = V_a - V_b$, calculated using the techniques I am showing you today.

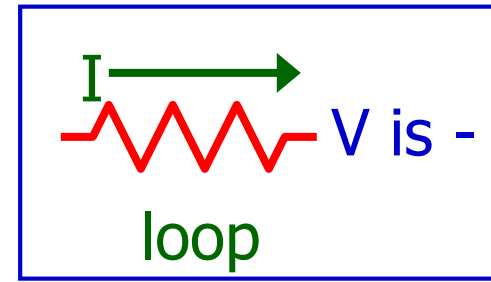
(Terminal voltage is usually expressed as a positive number, so it is better to take the absolute value of V_{ab} .)

*Remember, all sources of emf—not just batteries—have an internal resistance.

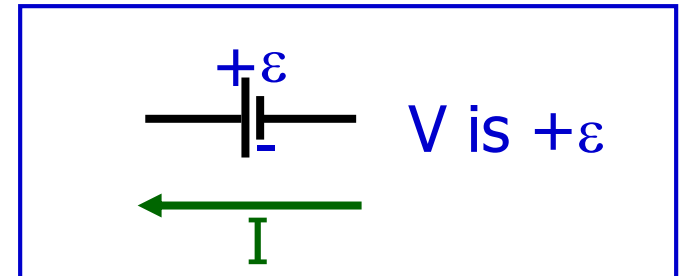
Summary of procedures for tomorrow's homework:

Draw the current in a circuit so that it flows from $-$ to $+$ through the battery. The sum of the potential changes around a circuit loop is zero.

Potential decreases by IR when current goes through a resistor.



Potential increases by ε when current passes through an emf in the direction from the $-$ to $+$ terminal.



Treat a battery internal resistance like any other resistor. If I flows through a battery $+$ to $-$, potential decreases by ε .

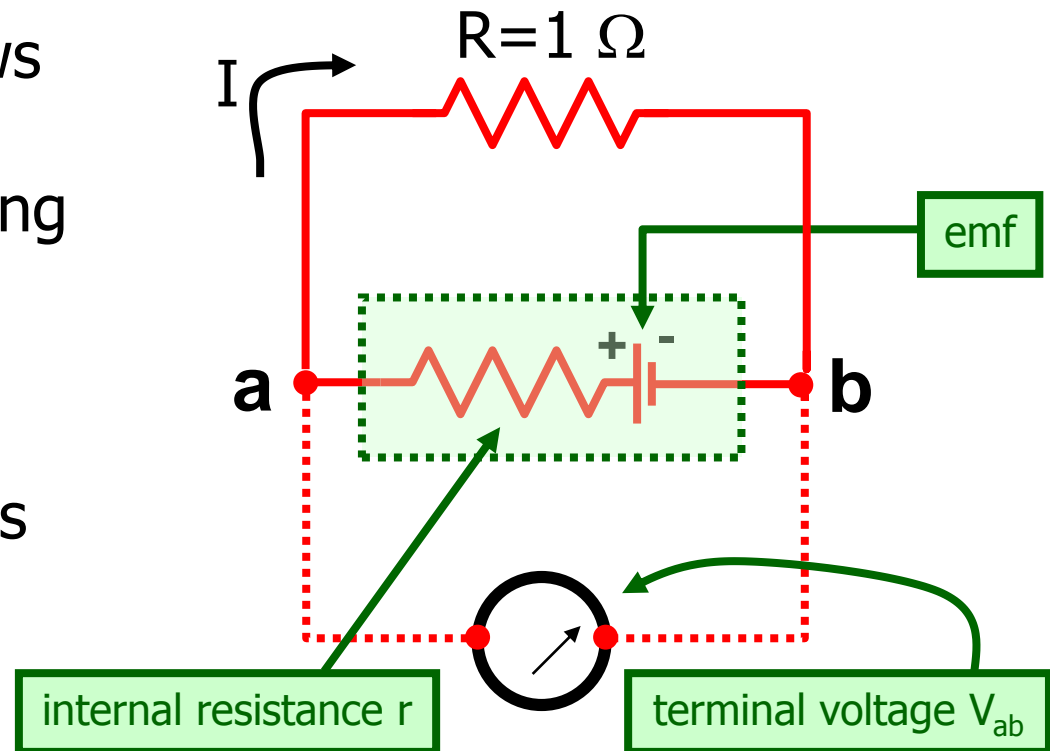
Example: a battery is known to have an emf of 9 volts. If a 1 ohm resistor is connected to the battery, the terminal voltage is measured to be 3 volts. What is the internal resistance of the battery?

Because the voltmeter draws "no" current, r and R are in series with a current I flowing through both.

$$\varepsilon - Ir - IR = 0$$

IR , the potential drop across the resistor R , is also the potential difference V_{ab} .

$$V_{ab} = IR$$



the voltmeter's resistance is so large that approximately zero current flows through the voltmeter

$$\varepsilon - Ir - IR = 0$$

$$V_{ab} = IR$$

$$Ir = \varepsilon - IR$$

$$I = \frac{V_{ab}}{R}$$

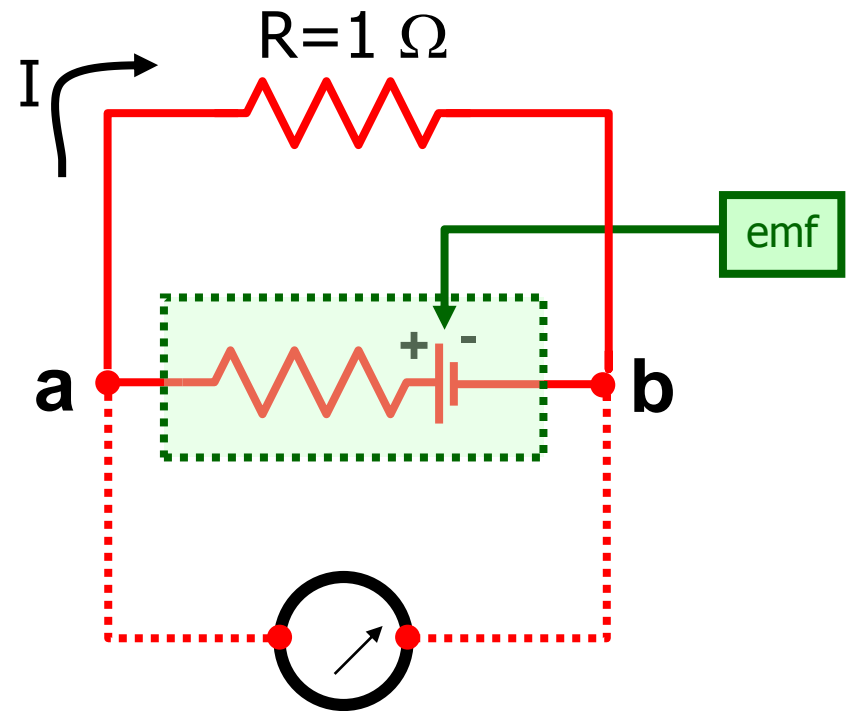
$$r = \frac{\varepsilon - IR}{I}$$

$$r = \frac{\varepsilon}{I} - R$$

$$r = \frac{\varepsilon R}{V_{ab}} - R$$

$$r = R \left(\frac{\varepsilon}{V_{ab}} - 1 \right)$$

$$r = 1 \left(\frac{9}{3} - 1 \right) = (3 - 1) = 2\Omega$$



A rather unrealistically large value for the internal resistance of a 9V battery.

By the way, the experiment described in the previous example is not a very good idea.

$$I = \frac{V_{ab}}{R}$$

$$I = \frac{3}{1} = 3A$$

I may do a demo on this some time.