"We live in a truly magical time. With a flick of a finger, the power of ten horses flows from a small wire in the wall of our homes to clean our carpets."

--Steven Chu
Why do electric companies make power lines with very high voltages to deliver electricity to your house?

Let’s make some estimations:

\[ R = 10\Omega, \quad V = 100,000\text{V} \text{ to deliver } 100\text{kW of power.} \]

First, don’t make a common mistake:

\[
P_{\text{dis}} = \frac{V^2}{R} = \frac{(100,000\text{V})^2}{10\Omega} = 1.0 \times 10^9\text{W}
\]

This equation can only be used with a potential difference (\(\Delta V\)) across a resistor.
Instead we will find the current by the power transfer equation.

\[ P = IV \]

\[ I = \frac{P}{V} = \frac{100\text{kW}}{100,000\text{V}} = 1\text{A} \]

Now we can input this current in the proper power dissipation equations.

\[ P_{\text{dis}} = I^2R = (1\text{A})^2 10\Omega = 10\text{W} \]

This only represents a 0.01\% loss of power transferred to resistive effects (not bad!).
Power

What if power companies used lower potential for their transmission lines (say 2,000V)?

\[ P = IV \]

\[ I = \frac{P}{V} = \frac{100\text{ kW}}{2,000\text{V}} = 50\text{A} \]

Now we can input this current in the proper power dissipation equations.

\[ P_{\text{dis}} = I^2R = (50\text{A})^210\Omega = 25,000\text{W} \]

25% of power is lost to heat. That isn’t good business.
Superconductors can help solve these problems.

Superconductors are materials whose resistance falls to virtually zero below a certain critical temperature, $T_c$.

Once a current is set up in a superconductor, it persists without any applied potential difference.
Superconductors

Above $T_c$, the superconductor acts as a normal metal.

Unfortunately superconductors currently only exist at low temperatures (highest $\sim 150K$) $[-123^\circ C]$.

But we are getting closer to room temperature superconductivity. In the mid-80’s the highest was near 30K $[-243^\circ C]$. 
Circuits

Light bulbs are resistors that you can measure the power dissipated by them with their brightness.

The brighter the bulb, the more power dissipation of the light bulb.

I have two light bulbs, one 100W and one 60W. If I hook them up separately to the a given battery which one will be brighter?

Correct, the 100W bulb was brighter!

What if I hook them up in series to the same battery, which one will be brighter then?
Conceptual Question

I have two light bulbs, one 100W and one 60W. If I hook them up in series to the same battery, which one will be brighter?

A) The 100W bulb.

B) The 60W bulb.

C) They will have the same brightness.

D) It doesn’t matter what power rating they have it will always be the one that is closest to the positive terminal of the battery.
Circuits

- The 60W bulb rating is not always the power dissipated.
- Realize that the power rating on light bulbs only represent the power dissipated when they are plugged into the wall.
- A 75W bulb will not always put out 75W of power dissipation.
- You have to know what the potential difference source is and what other elements are in the circuit.
- When examining a circuit you need to know all of the elements in the circuit (think globally).
Circuits

We will now start discussing how current, resistance, power, and devices work together as a circuit.

First, become familiar with the following symbols that make circuit diagrams easy to draw.
Batteries

There are three basic types of emf:

1) Ideal Battery: a battery that lacks internal resistance.

2) Real Battery: a battery that contains internal resistance, $r$, that hampers current flow.
   
   Note the internal resistance is in series with the battery.

3) Generator: a device that uses mechanical energy to create electrical energy.
Circuits

A typical circuit problem is to solve for the power/voltage/current at a specific point (like at a resistor).

This simplest circuit to calculate the current for is the following:

Using Ohm’s Law we find that:

\( \Delta V = IR \)

\( \varepsilon = IR \)

\( I = \varepsilon/R \)
Circuits

Technically, this is the only circuit you can use Ohm’s Law to solve for the current through the resistor.

But we can take more complicated circuits and reduce them down this simple circuit and then apply Ohm’s Law.

A typical task is to find the current in a circuit and, maybe, then find the power dissipated by various circuit elements.

We will use the same ideas that we developed when finding out the equivalent capacitance for a given circuit.
Circuits

Let's say we have a circuit with two resistors in series.

When these two resistors are hooked up to the battery, a current is then established.

In this circuit, the amount of current moving through $R_1$ equals the amount of current moving through $R_2$ (and the same as the battery as well).

$I_{bat} = I_{R1} = I_{R2} = I$
Circuits

Each resistor will have a voltage drop across it.

But the straight part of the wire will not have any potential differences.

This means that: \( \Delta V_{bat} = \Delta V_{ac} \)

The potential difference across either resistor will sum to be the potential difference across the battery.

\( \Delta V_{bat} = \Delta V_1 + \Delta V_2 \)
Circuits

We can essentially replace the two resistors in series with one equivalent resistor.

The battery sees current, $I$, passing through it and believes that the one equivalent resistor has a potential difference of $\Delta V_{bat}$.

So, to the battery the equivalent resistance is:

$$R_{eq} = \frac{\Delta V_{bat}}{I}$$

$$R_{eq} = \frac{\Delta V_1 + \Delta V_2}{I}$$
Circuits

This becomes:

\[ R_{eq} = \frac{\Delta V_1}{I} + \frac{\Delta V_2}{I} \]

\[ R_{eq} = R_1 + R_2 \]

The equivalent resistance of resistors in series is greater than the individual resistors.

In general, for series resistors:

\[ R_{eq} = R_1 + R_2 + R_3 + \ldots \]
Circuits

Let’s say we have a circuit with two resistors in parallel.

When these two resistors are hooked up to the battery, a current is then established.

In this circuit, both resistors would have the same potential difference as the battery.

$$\Delta V_{bat} = \Delta V_1 = \Delta V_2$$
Circuits

As the current, I, approaches point a (a junction), it will break up into $I_1$ and $I_2$.

\[ I = I_1 + I_2 \]

We can essentially replace the two resistors in parallel with one equivalent resistor.

The battery sees current I passing through it and believes that the one equivalent resistor has a potential difference of $\Delta V_{\text{bat}}$. 

![Circuit diagram](image)
Circuits

So, to the battery the equivalent resistance is:

\[ R_{eq} = \frac{\Delta V_{bat}}{I} \]

\[ \frac{1}{R_{eq}} = \frac{I}{\Delta V_{bat}} \]

\[ \frac{1}{R_{eq}} = \frac{I_1 + I_2}{\Delta V_{bat}} \]

\[ \frac{1}{R_{eq}} = \frac{I_1}{\Delta V_1} + \frac{I_2}{\Delta V_2} \]

In general, for parallel resistors:

\[ \frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots \]