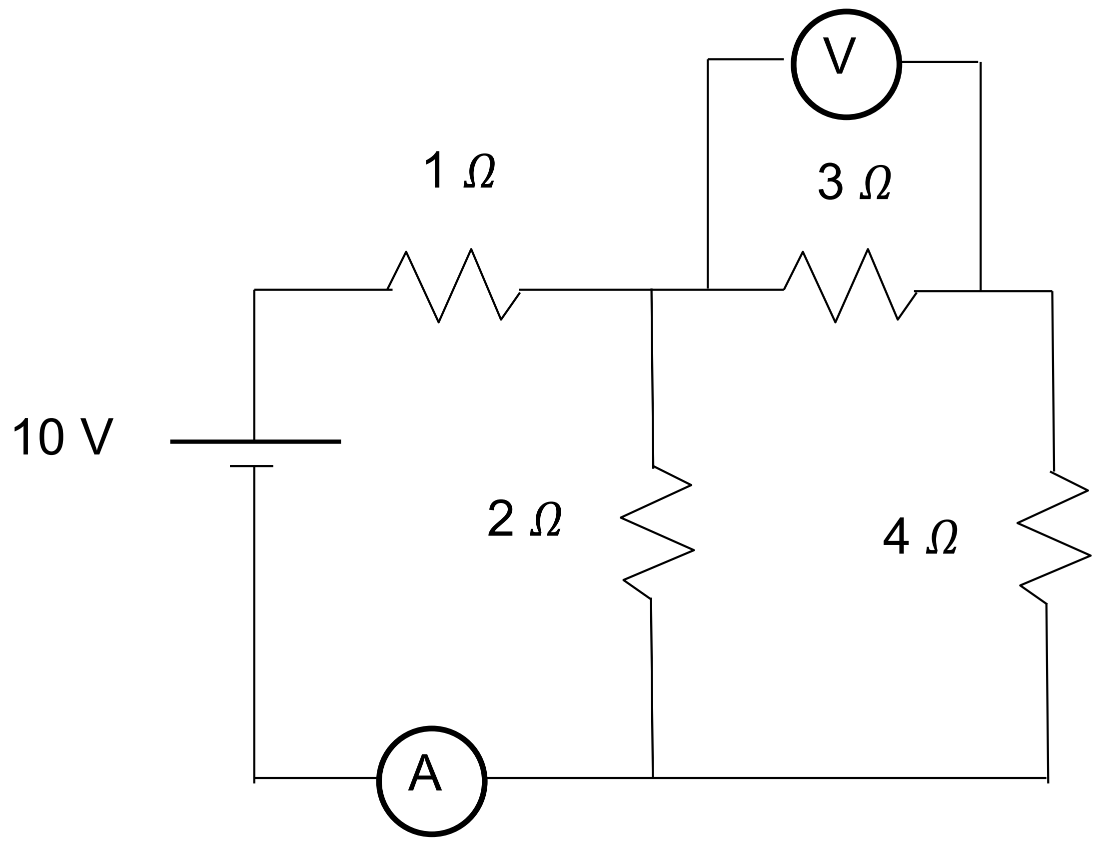
General announcements

- Today:
  - Talk about Ohm's Law lab write up - due **next Wednesday 2/20**
    - Formal lab: cover page, blurbs, graphs, data table…

- Check MyPoly - calendar has been updated through Spring Break
  - Next test is Monday 2/25

Back to the island...

- What do each of the meters read?

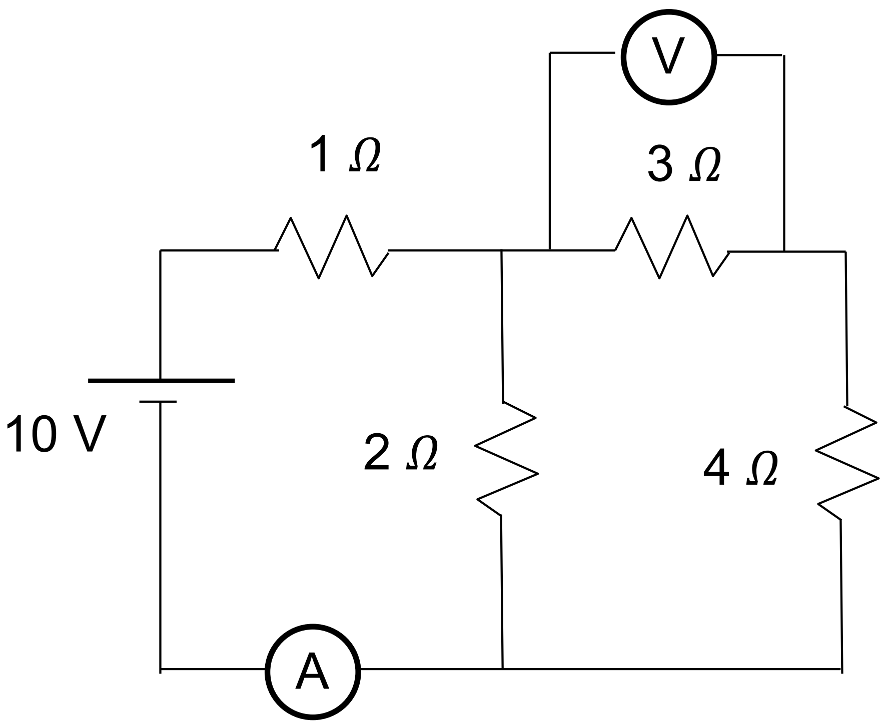


Analyzing a complex circuit by the “seat of your pants”

- First step will almost always be to find the equivalent resistance of the circuit
  - This allows you to find the current through the battery, e.g. the total current in the circuit
  - Remember to break down internal pieces step by step, redrawing the circuit if necessary, to find total resistance
  - Also remember that ammeters and voltmeters are irrelevant to the behavior of the circuit! They merely measure what’s going on.
- Then, use Ohm’s Law on as many segments as needed to find the current through a particular branch and/or the voltage across a resistor. Repeat!
- *There is a more formal way to do this we will learn in a bit. This is the ”seat of your pants” way that can work for moderately complex circuits.*

So this island one…

What do each of the meters read?



Find the equivalent resistance:

$$R_{eq} = 1\Omega + \frac{1}{\frac{1}{2\Omega} + \frac{1}{(3\Omega + 4\Omega)}} = 2.55\Omega$$

Find the total current through the battery:

$$I = \frac{10\ V}{2.55\ \Omega} = 3.92\ A$$

So the ammeter reads **3.92 A**.

If we can find the current through the 3*Ω* resistor, we can use Ohm's law to find the potential difference. So:

$$\Delta V_{1\Omega} = (3.92A)(1\Omega) = 3.92\ V$$

so $\Delta V_{2\Omega} = \Delta V_{3+4\Omega} = 10V - 3.92V = 6.08\ V$

$I_{2\Omega} = \frac{6.08V}{2\Omega} = 3.04\ A$ which means of the total 3.92 A, almost all is going through the 2*Ω* resistor, and 3.92A - 3.04 A = 0.88 A is in the other branch.

Finally, since $I_{3\Omega}$=0.88 A, $\Delta V_{3\Omega} = (0.88A)(3\Omega) =$ $\mathbf{2.64\ V}$

Conceptual questions

13.20) In the circuit in Figure II, the current through the 12 Ω resistor is .5 amps.

- **a.)** What is the current through the 8 Ω resistor?
- **b.)** What is the power supply's voltage?

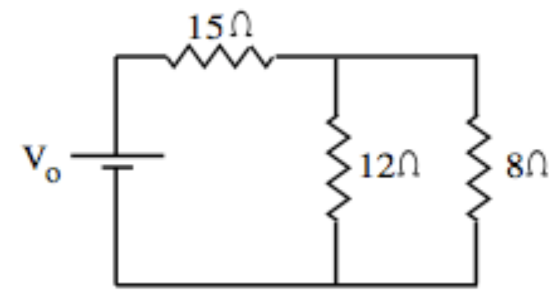


FIGURE II

13.21) In Figure III, R_2 is decreased. Assuming an ideal power supply, what happens to:

- **a.)** R_2's voltage;
- **b.)** R_2's current;
- **c.)** R_1's voltage;

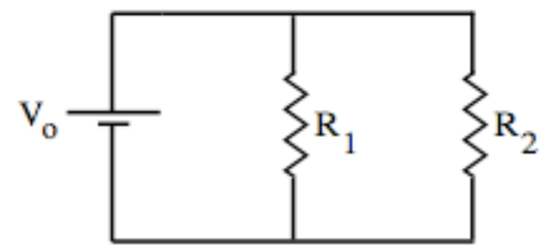


FIGURE III

From Fletch's book - solutions on his website

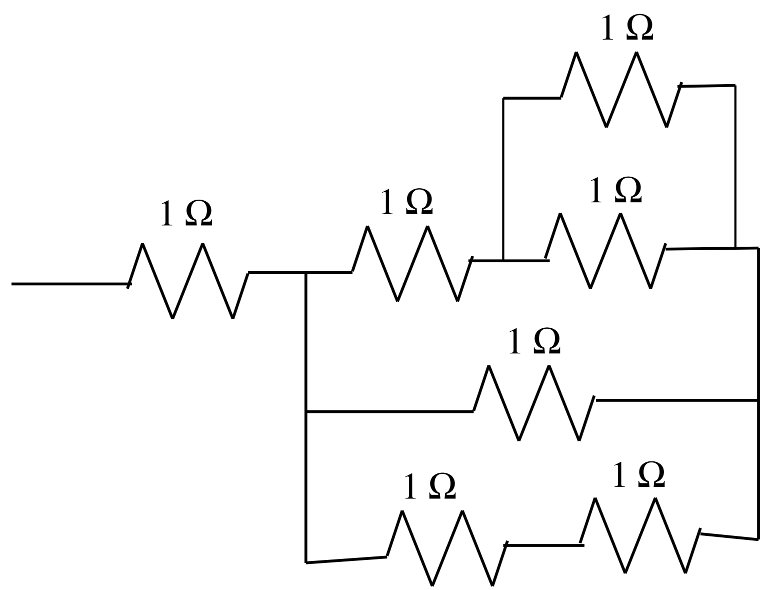
More conceptual questions

13.27) Using as many 12 Ω resistors as you need, produce a resistor circuit whose equivalent resistance is:

a.) 18 Ω; and

b.) 30 Ω.

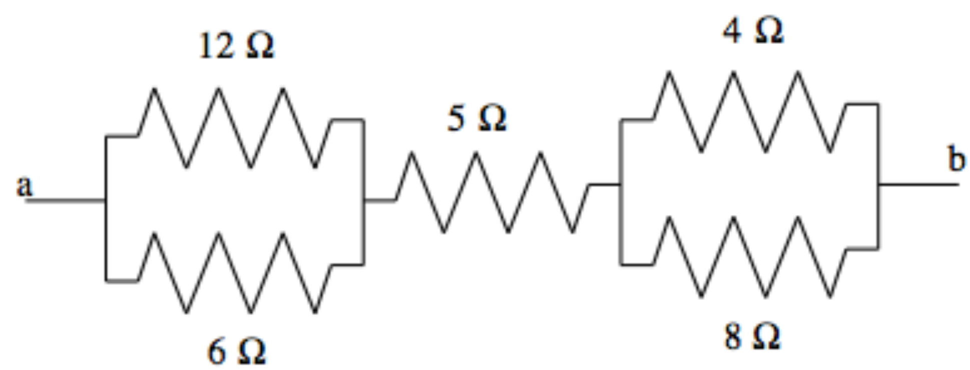
Where are we going with this? Complex circuits - like this one! How would you go about finding the equivalent resistance of this circuit?



Problem 18.6

Problem 18.6

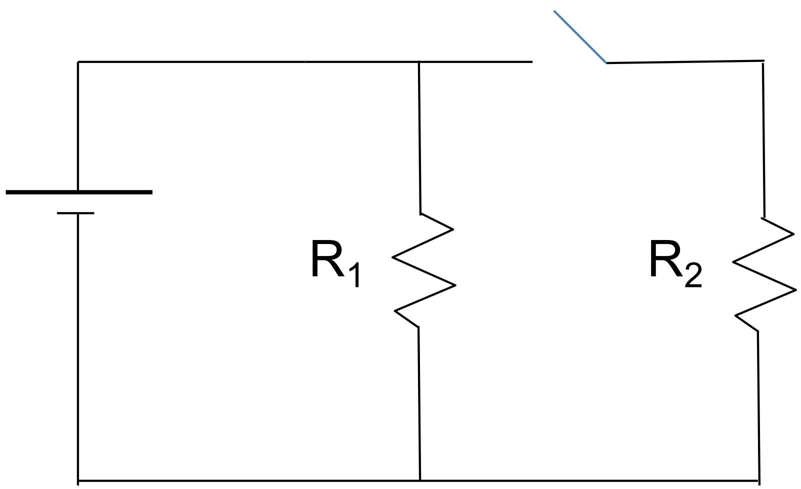
a.) Equivalent resistance?



b.) If the voltage between “a” and “b” is 35 volts, what are the currents through each branch.

Parallel circuit with a twist!

- Consider the circuit below (also set up at the front of the class). The switch is initially <u>open</u> and current I_0 flows through the bulb and battery. What will happen when the switch is <u>closed</u> in terms of bulb brightness and current in each part of the circuit?

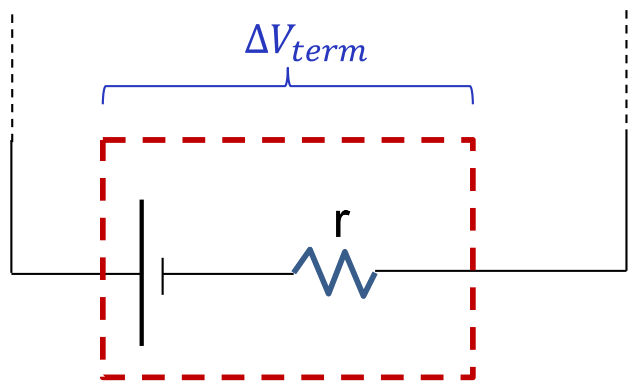


- We observe that both bulbs are lit equally, about as bright as R_1 was before! Why?
  - Connecting a branch in parallel doesn't change the voltage drop across R_1, and thus the current through it hasn't changed, either!

- Why does R_1 dim slightly, then???

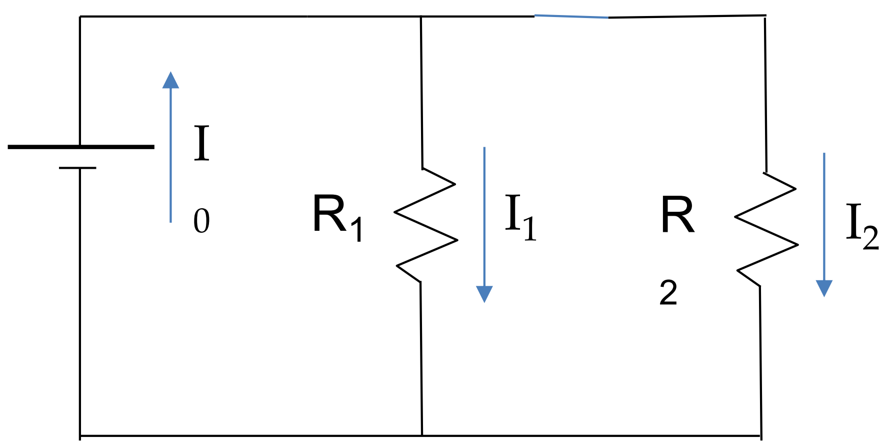
Internal resistance

- A battery is not a perfect voltage source - when current is flowing, it has a tiny amount of internal resistance which decreases its effective voltage in the circuit.
- The total energy per unit charge a battery can produce when no current is flowing is called its **electromotive force**, or **emf ($\boldsymbol{\varepsilon}$)**
  - This is measured in Volts (still energy/charge)
- When a current *I* is flowing through the battery, the small amount of internal resistance ***r*** (little r to distinguish from a resistor R in a circuit) reduces this emf by an amount ***Ir***. This means the effective, or **terminal voltage** of the battery is equal to: $\Delta V_{term} = \varepsilon - Ir$



Back to parallel circuit

- So in that parallel circuit, why does the first bulb dim when another is connected?



When only R_1 is connected, $I_0 = I_1$.

When R_2 is connected, I_0 increases to be I_1+I_2 -- this increases the current through the battery.

That increase means the Ir term of the internal resistance <u>also</u> increases! The emf of the battery is unchanged, but the greater Ir term means the terminal voltage actually drops slightly, which reduces the voltage across R_1, so it's not quite as bright!

Wait a minute, what does brightness have to do with anything…?

Power

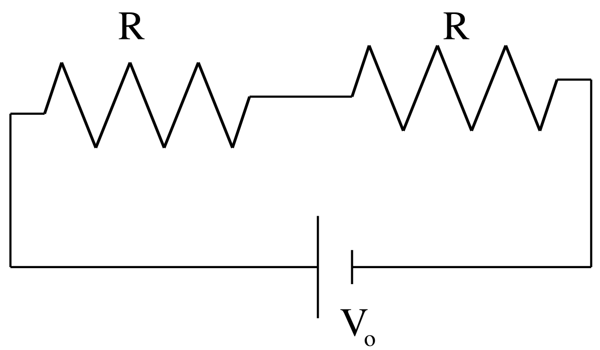
- Power in an electrical circuit is the rate at which energy is transformed into other forms (e.g. from electrical energy into heat/light/etc.)
- Remember that power = work/time, and work = qV soooo

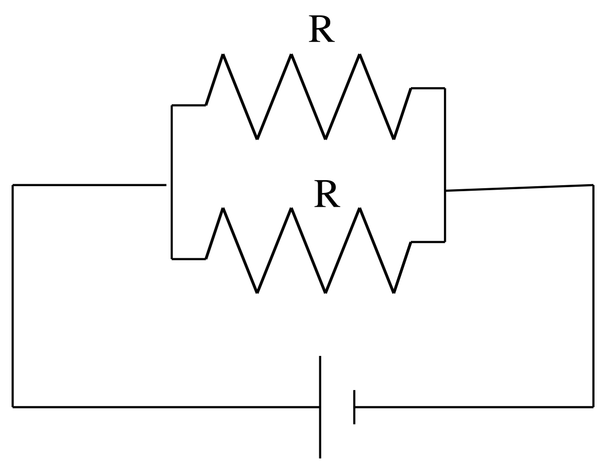
$$P = \frac{qV}{t} = IV$$

- Substituting from Ohm's Law, we can also say $P = IV = I^2R = V^2/R$
  - Which one you want depends on what you need. If you know $P = IV$ and $V = IR$, you can always substitute!

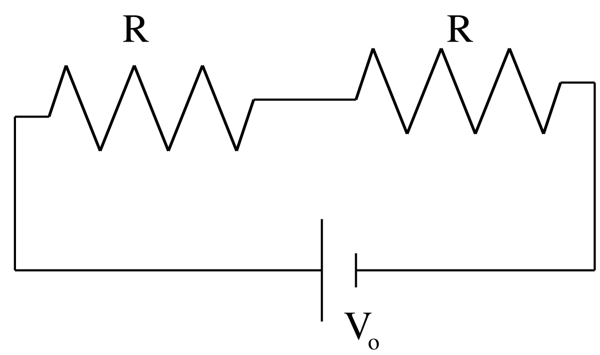
Power example #1

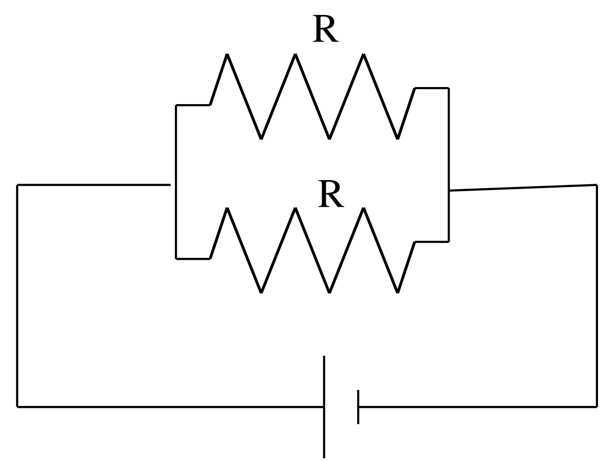
Two resistors each of magnitude R are wired in series across a battery of voltage V_0. In this configuration, it is observed that the power dissipated by the resistor combination is 5 W. If the same resistors are then place in a parallel combination and put across the same power supply, how much power will then dissipate?





Power example #1





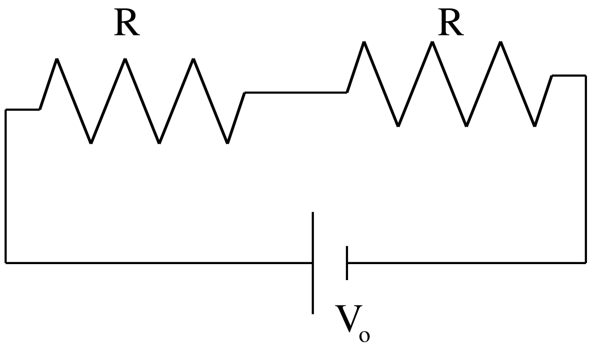
The key is in noticing two things. First, by changing the arrangement of resistors we've changed the equivalent resistance of the circuit. Second, with the equivalent resistance having changed, the current through the combination will change. They two changes are important because the power is related to both the net size of the resistance dissipating the power AND the current through that resistance (both of which have changed).

Start by determining the equivalent resistance of each combination:

$$R_{series} = 2R$$

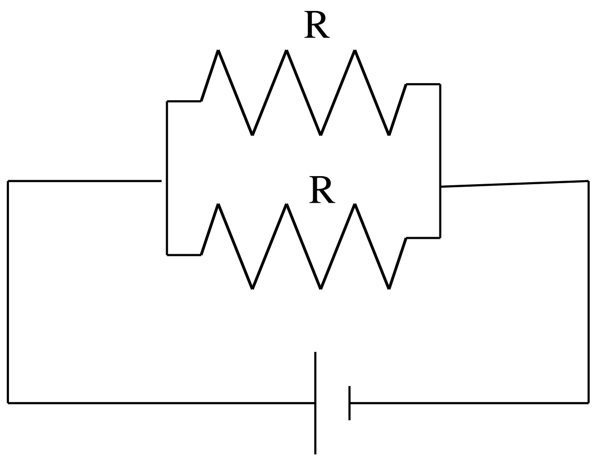
$$R_{parallel} = \frac{R}{2}$$

Power example #1



With the equivalent resistance for the series combination, we can assume it draws i_o worth of current so that it's power rating will be:

$$P_{series} = i_o^{\,2}(2R)$$
$$\Rightarrow \quad 5 = i_o^{\,2}(2R)$$
$$\Rightarrow \quad i_o^{\,2}R = 2.5$$



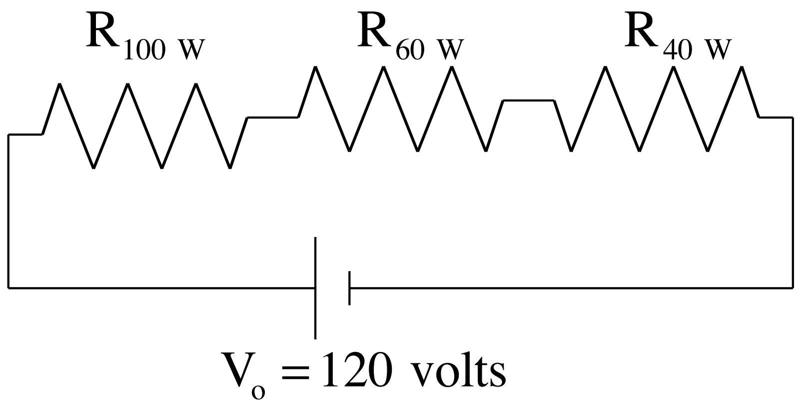
The equivalent resistance of the parallel combination is a quarter as large as the equivalent resistance of the series circuit, so that circuit will draw 4 times as much current as the series combination. Doing the power relationship for that, then, we get:

$$P_{parallel} = (4i_o)^2\left(\frac{R}{2}\right)$$
$$= 8\, i_o^2 R$$

But $i_o^2 R = 2.5$, so evidently $P_{parallel} = 8\, i_o^2 R = 8(2.5 \text{ watts}) = 20\text{watts}$. In other words, the power dissipated is 4 times greater for the one circuit than the other.

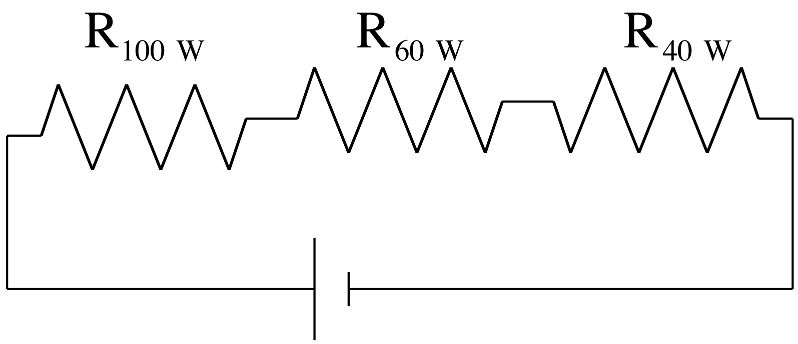
Power example #2

How will the brightness of the bulbs compare?



Power example #2

How much resistance does each bulb present when running normally?



For the 100 watt resistor:

$$P_{100\ W} = iV$$
$$\Rightarrow \quad (100\ w) = i(120\ v)$$
$$\Rightarrow \quad i_{100\,W} = .833\ A$$

$$\Longrightarrow$$

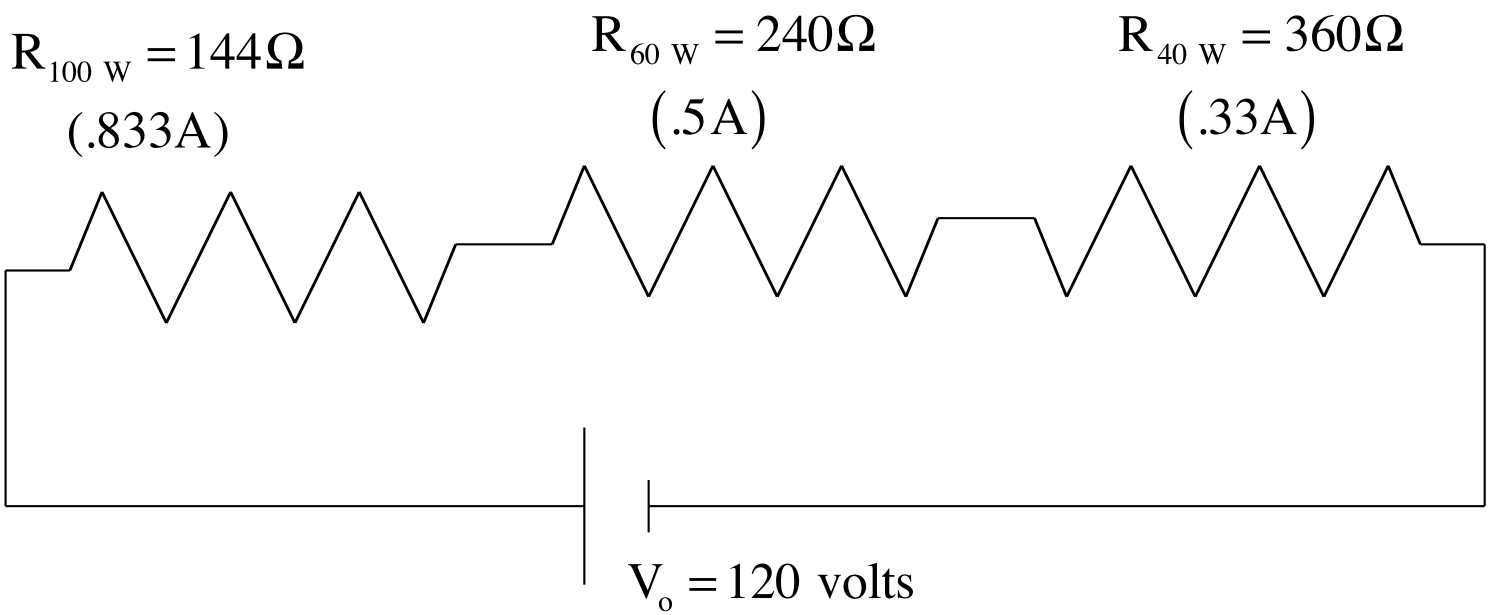
$$P_{100\ W} = i^2 R_{100\,W}$$
$$\Rightarrow \quad (100\ w) = (.833\ A)^2 R$$
$$\Rightarrow \quad R_{100\,W} = 144\ \Omega$$

Similar calculations for the other two resistors results in:

$$P_{60\ W} = iV$$
$$\Rightarrow \quad (60\ w) = i(120\ v)$$
$$\Rightarrow \quad i_{60\,W} = .5\ A$$
$$\Rightarrow P_{60\ W} = i^2 R_{60\,W}$$
$$\Rightarrow \quad (60\ w) = (.5\ A)^2 R_{60\,W}$$
$$\Rightarrow \quad R_{60\,W} = 240\ \Omega$$

$$P_{40\ W} = iV$$
$$\Rightarrow \quad (40\ w) = i(120\ v)$$
$$\Rightarrow \quad i_{40\,W} = .33\ A$$
$$\Rightarrow P_{40\ W} = i^2 R_{40\,W}$$
$$\Rightarrow \quad (40\ w) = (.33\ A)^2 R_{40\,W}$$
$$\Rightarrow \quad R_{40\,W} = 360\ \Omega$$

Power example #2



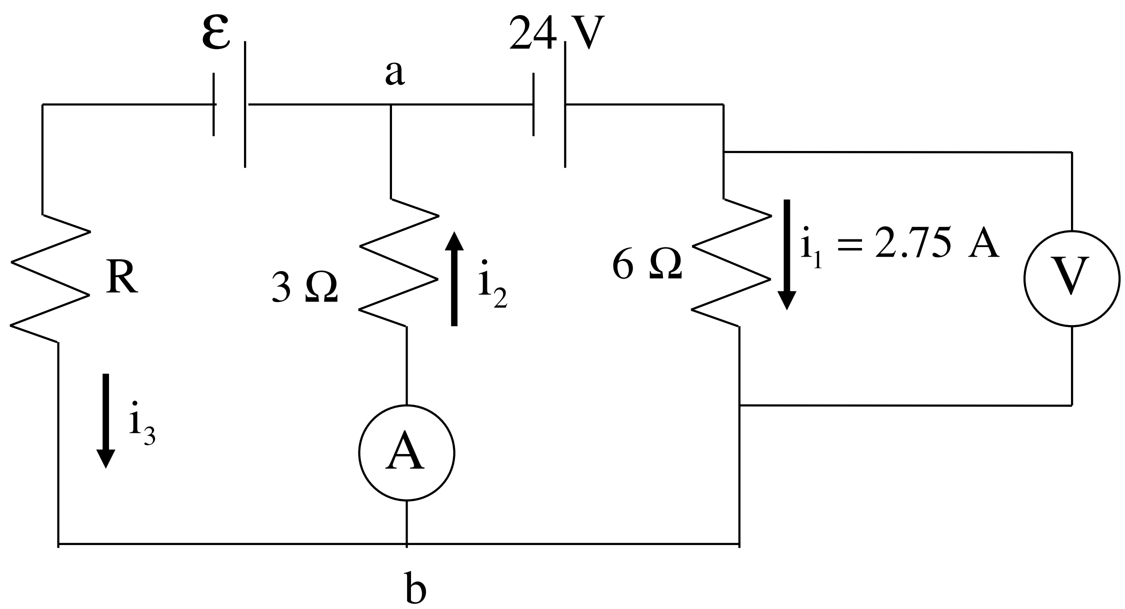
The actual current is:

$$i = \frac{V_o}{R_{eq}}$$

$$= \frac{120}{(144\Omega)+(240\Omega)+(360\Omega)}$$

$$= .16\ A$$

Example 7: Consider:



a.) *What does* the voltmeter read?

$$V = i_1 R$$
$$= (2.75\,A)(6\ \Omega)$$
$$= 16.5\ V$$

b.) *What is* the voltage difference between *Points a* and *b*?

Assuming the voltage at *Points a* is zero (this is tricky as you don't know what is—you can define it anyway you want, though), the voltage changes will be due to the increase due to the battery in the right branch and the drop due to the 6 ohm resistor. That is:

$$V_{ab} = 24 - (2.75\,A)(6\ \Omega)$$
$$= 7.5\ V$$

c.) *What does* the ammeter read?

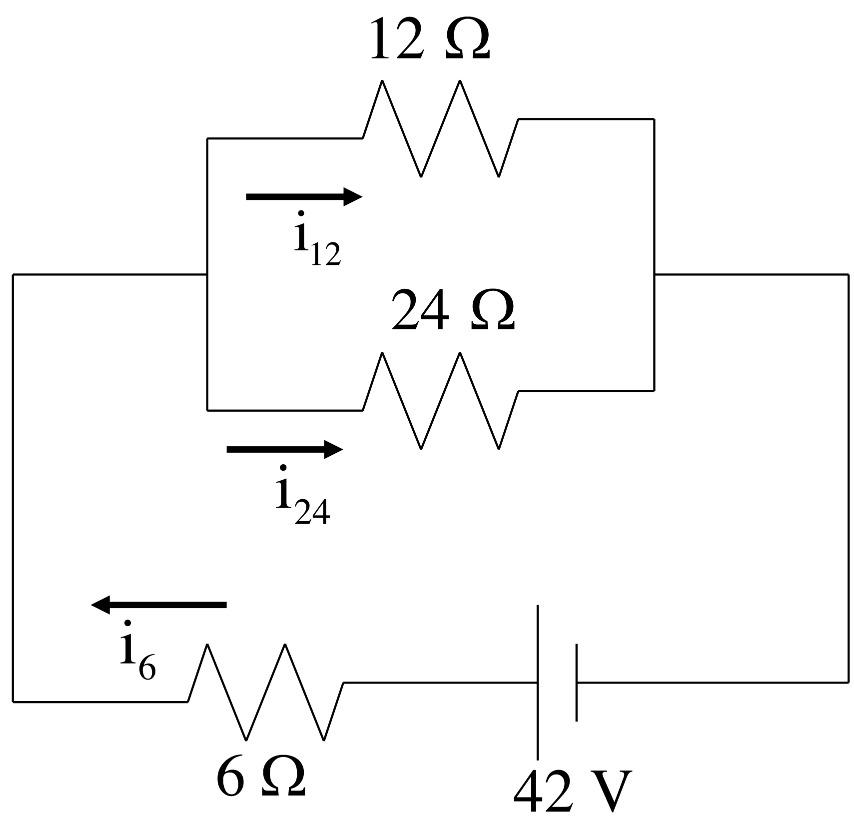
This is just the *current* through the 3 ohm resistor, or:

$$V_{ab} = i_2 R_3$$
$$7.5V = i_2 (6\ \Omega)$$
$$\Rightarrow \quad i_2 = 1.25\ A$$

d.) *How is* i_1 generated? *Each battery produces* an E-fld, which permeates the entire circuit. The fields superimpose on one another, creating a net field. That net field is what motivates charge to move in each branch.

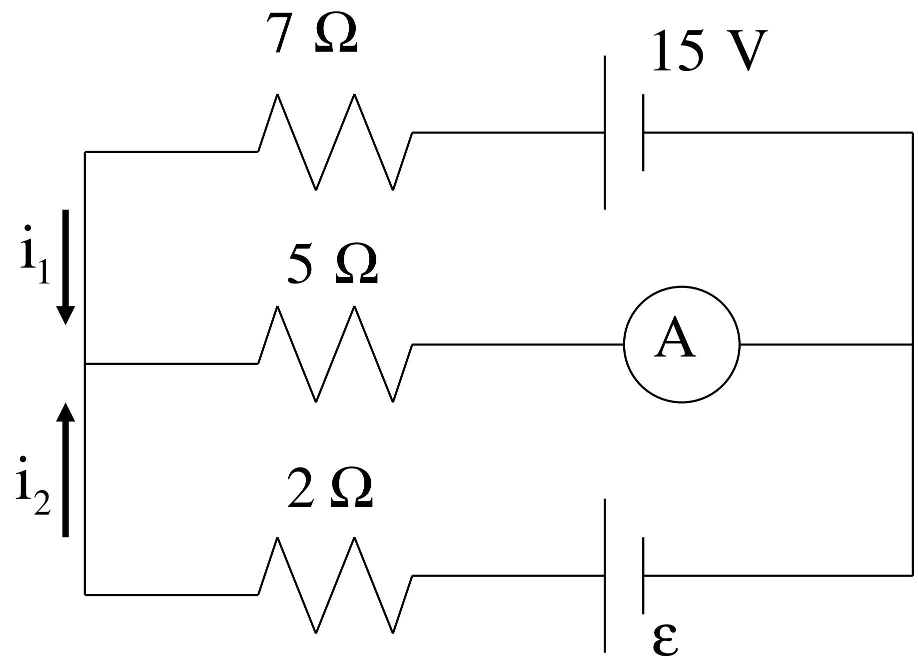
Problem 18.16

Use seat of pants method to determine each current.



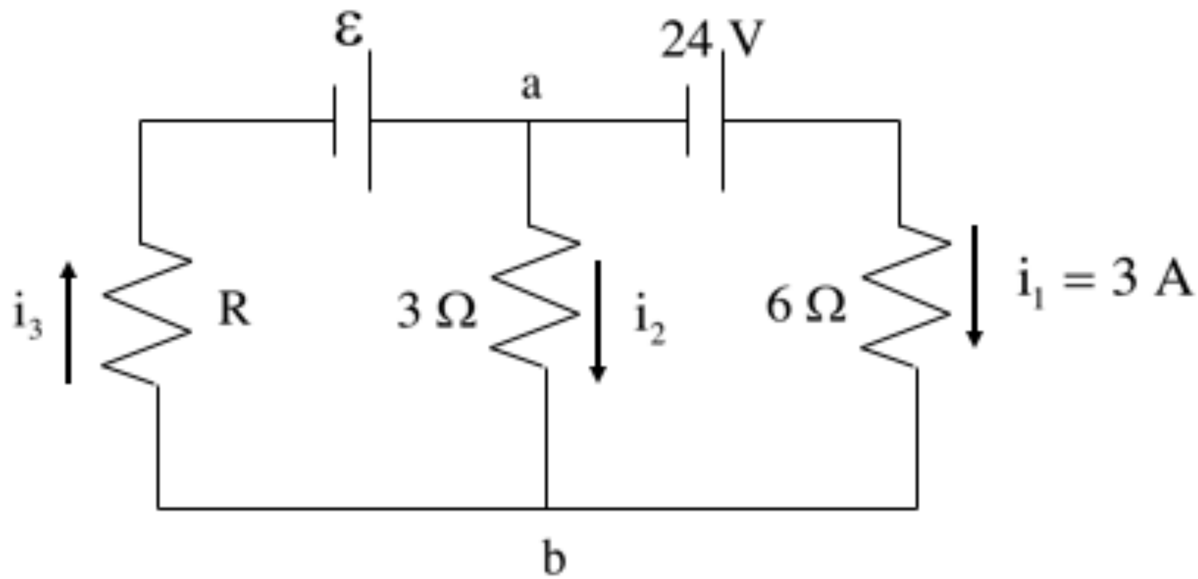
Problem 18.17

Ammeter reads 2 amps. What are unknown values?



Problem 18.20

What is the voltage difference across *a*-*b,* and what are the currents in the circuit?



More conceptual fun!

13.14) Without changing anything else, you double the current through a resistor. How will that affect the power being dissipated by the resistor?

13.15) You have a resistor attached to an ideal power supply. You halve the resistance of the resistor. How will that affect the power being dissipated by the resistor?

13.17) You have a 10 watt light bulb and a 20 watt light bulb hooked in series in a circuit. Which bulb would you expect to have the greater resistance?

One more power question...

The power dissipated by two resistors in series is 48 watts. How much power will be dissipated by the same two resistors if they are put in parallel?

Solution part 1

Noting that the equivalent resistance of the series combination is 2R, what can we write about the two resistors in series?

$$P = i^2 R_{net}$$
$$\Rightarrow \quad 48 = i^2 (2R)$$
$$\Rightarrow \quad 24 = i^2 R$$

To begin with, the equivalent resistance of the new circuit with the resistors in parallel will be R/2. With that bit of information, what can we say about the new current?

Solution part 2

If the series equivalent resistance is 2R and the parallel equivalent resistance is R/2, the net resistance has changed due to the circuit change by 1/4. That means the current in the parallel circuit has gone up by 4. Sooo, for the second circuit we can write:

$$P_{new} = (4i)^2 R_{new}$$

$$\Rightarrow \quad P_{new} = (4i)^2 (R/2)$$

$$\Rightarrow \quad P_{new} = 8(i^2 R)$$

$$\Rightarrow \quad P_{new} = 8(24 \text{ V})$$

$$\Rightarrow \quad P_{new} = 192 \text{ watts}$$