CHAPTER 13 -- AC & DC CIRCUITS

QUESTION & PROBLEM SOLUTIONS

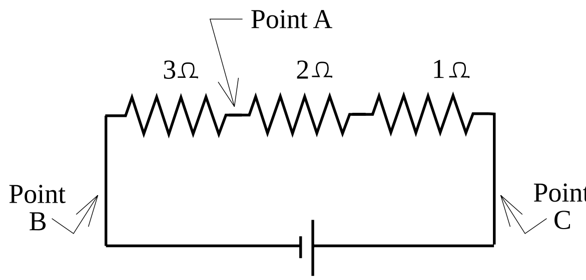
13.1) What is the difference between voltage and current in a DC circuit?

Solution: You are given a 10 volt battery to work with in lab. The fact that the battery is 10 volts--what does that tell you? It tells you the voltage DIFFERENCE between the terminals of the battery. This is an *energy* related quantity (remember, the *work per unit charge* available as you go from one point to another in an electrical potential field is $W/q = -\Delta V$ . . . voltage differences are work, hence energy, related). In short, the voltage associated with any electrical element tells you the amount of energy (per unit charge) the element either provides to the circuit (example: a power supply) or removes from the circuit (example: a resistor in the form of a light bulb). Voltages are always measured *across* elements. If you are dealing with a resistor (i.e., light bulb, toaster, whatever), this difference registered in the direction of current flow will always be a voltage *drop* across the resistor (that is, current always leaves the low voltage side of the resistor). Voltage drops in this context denote a loss of energy to the circuit (or, more accurately, a conversion of electrical energy to some other form of energy--light, heat, whatever). As for current, it measures flow rate. It tells you how much charge passes by a point or through an element *per unit time*. Its units are *coulombs/second*. Summarizing, *voltages* or, more accurately, *voltage drops* exist ACROSS ELEMENTS whereas *currents* pass THROUGH ELEMENTS.

13.2) A 12 ohm resistor has 2 amps of current passing through it. How much work does the resistor do on an electron moving through the resistor?

Solution: The voltage difference across a resistor is proportional to the current through the resistor with the proportionality constant being the resistor's resistance. Mathematically, this is $V = iR$. A 12Ω resistor with *2 amps* flowing through it exhibits a voltage drop of $V = (2\ amps)(12\ \Omega) = 24\ volts$. If you will remember, a voltage difference is equal to the *work per unit charge* or, in this case, the *energy per unit charge*, dropped by the resistor. Again, mathematically, this means $W/q = -\Delta V$. Although it is possible to get confused with signs here, the easiest way to do this is to deal with magnitudes, then decide whether energy is being supplied (*positive* work) or removed (*negative* work) by the element. Since an electron has a charge equal to 1.6×10^{-19} Coulombs, the magnitude of the work done on it will be $qV = (1.6\times10^{-19} C)(24\ joules/C)$ = . . . whatever (I don't have my calculator with me). The point is that *voltage differences* are related to energy and/or work (per unit charge) within the system.

13.3) There are 3 amps of current being drawn from a power supply. The circuit is comprised of three resistors as shown.



a.) In what direction will current flow in this circuit?

Solution: By definition, current flows from high voltage to low voltage. Looking at the symbol used for the power supply in the circuit, the high voltage (positive) terminal is shown on the right with the low voltage (negative) terminal on the left. That means that in this case, the current will flow counterclockwise.

b.) In what direction will electrons flow in this circuit?

Solution: Electrons flow from the negative terminal (the low voltage side of the power supply) to the positive terminal (the high voltage side of the power supply). In this case, that would be in the clockwise direction.

c.) Some might suggest that there is an apparent discrepancy between the answers to *Part a* and *b*. What is the problem, and why is this not really a discrepancy?

Solution: The problem seems to be that the directions are opposite to one another. In fact, this isn't a problem as the direction of current is defined as the direction *positive charge* would move if it *could* move through the circuit. You and I know that it's negative electrons that move in a wire, but if you hadn't been told that at some earlier age, you wouldn't have known that. The fact that they screwed up when they first defined the direction of current flow doesn't diminish the fact that we are looking at a model that works just fine if our goal is to predict how electrical elements will behave in electrical circuits under known conditions (i.e., will enough energy be provided to the toaster oven to toast the sourdough baguette . . . latidah!).

d.) What is the voltage across the power supply?

Solution: The equivalent resistance of the series combination is 6 ohms. Remembering that the current is the same through each of the series elements and that Ohm's Law works not only across each individual resistor but also across the whole combination (that is, the net voltage across the whole enchilada is equal to the current through the enchilada times the net resistance of the enchilada), we can write $V = iR_{equ} = (3\ A)(6\ \Omega) = 18\ volts$.

e.) What is the current at *Point A*?

Solution: I'm trying to trick you into wondering if the current is different at different points in the circuit. This is a *one loop* circuit. That means there is no place for charge flow to go except around the circuit. As such, the current at *any point in the circuit* will be the same as the current at any other point. In short, it's *3 amps*.

f.) What is the voltage drop across the 2 ohm resistor?

Solution: According to Ohm's Law, the voltage across a resistor is equal to the current through the resistor times the resistance of the resistor, or $V_R = iR$. For this situation, $V_{R=2} = (3\ A)(2\ \Omega) = 6\ volts$.

g.) What is the net voltage across the 1 ohm and 2 ohm resistors (combined)?

Solution: Again, Ohm's Law works here. The net resistance over which you want the voltage is equal to $3\ \Omega$, so $V_{2\&3combined} = (3\ A)(3\ \Omega) = 9\ volts$.

h.) How would the readings differ if you put an ammeter at *Point B* versus an ammeter at *Point C*?

Solution: Ammeters measure current, and as the current is the same throughout the circuit, the ammeter readings wouldn't differ at all.

i.) If this were, in fact, an actual circuit you had built, what might you do if you wanted to rearrange things so that the current drawn from the power supply doubled?

Solution: According to Ohm's Law (i.e., $V = iR$), for a given voltage source, halving the resistance would double the current. In this case, if you removed the $3\ \Omega$ resistor, the net resistance would halve and the current would double.

13.4) Your friend has built a circuit. She says that when she removes one resistor in the circuit, the current drawn from the ideal power supply goes up.

a.) What evidently happened to the effective resistance of the circuit when the resistor was removed?

Solution: If the current goes up, the net resistance must have gone down.

b.) Was the circuit a series or parallel combination?

Solution: In any circuit, if the current goes up, the net resistance must go down. To diminish the net resistance of a series combination, you have to remove a resistor. To diminish the net resistance of a parallel combination, you have to add a resistor. In this situation, a resistor was removed and the current went up, so we must be dealing with a series situation.

13.5) Your friend has built a circuit. He says that when he adds one resistor in the circuit, the current drawn from the ideal power supply goes up.

a.) What evidently happened to the effective resistance of the circuit when the resistor was added?

Solution: If the current goes up, the net resistance must go down.

b.) Was the circuit a series or parallel combination?

Solution: Again, in any circuit, if the current goes up, the net resistance must go down. To diminish the net resistance of a series combination, you have to remove a resistor. To diminish the net resistance of a parallel combination, you have to add a resistor. In this situation, a resistor was added and the current went up, so we must be dealing with a parallel situation.

13.6) What is common in series connections?

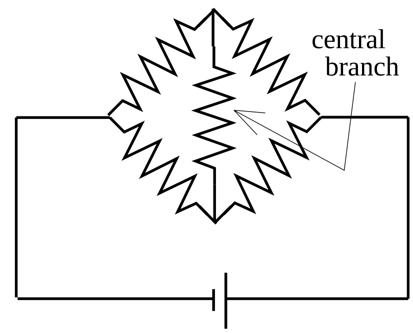
Solution: Current is common to each element in series, and each element is attached to its neighbor in one place only.

13.7) What is common in parallel connections?

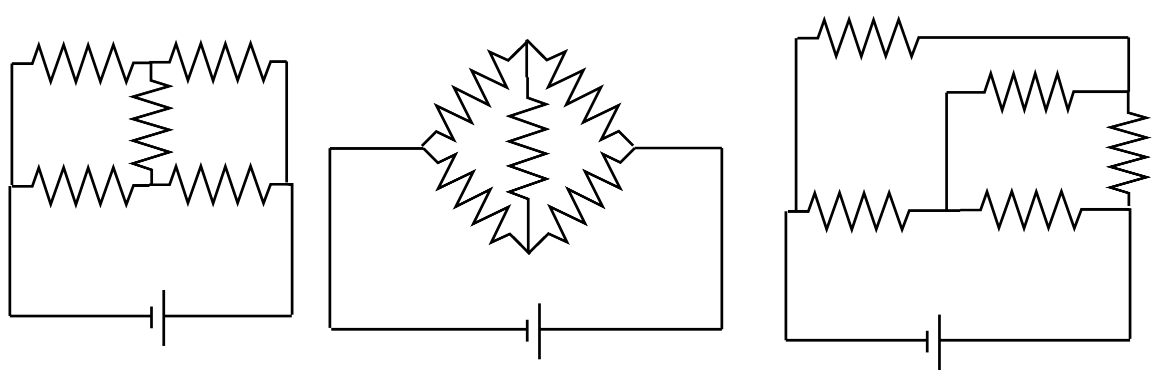
Solution: Voltage is common to each element in parallel, and each element is attached to its neighbor in two places (i.e., at each end).

13.8) You find that the current through the central branch of the circuit to the right is *zero*. What *must* be true of the circuit for this to be the case?

Solution: The only way to get zero current through a branch in a circuit is if there is no voltage difference between the two nodes bounding the branch. That is, the voltage at the top of the branch must equal the voltage at the bottom of the branch.



13.9) If you had to determine the current being drawn from the power supply in at least one of the circuits shown below, which circuit would you pick?

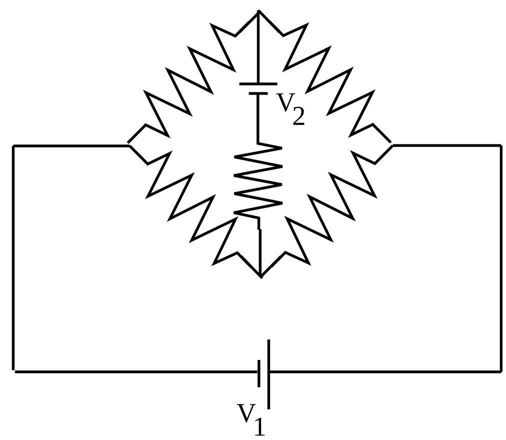


Solution: What's tricky about this question is that all of the circuits are the same. All I've done is add extra wire here and rearrange the general look of the connections there, and voilá, three circuits that look different but are, in fact, the same. Look at the sketches and see if you can identify which resistor matches up with which resistor.

13.10) Charge carriers don't move very fast through electrical circuits. For instance, in a car's electrical system, charge moves at an incredibly slow 100 seconds per centimeter (that's a velocity of .01 cm/sec). So why do car lights illuminate immediately when you turn them on?

Solution: When you throw an electrical switch, you create a voltage difference across the leads of the circuit. This serves to create an electric field through the circuit's wire. That electric field sets itself up at nearly the speed of light, so almost instantaneously the charge carriers in the circuit ALL feel the effect and begin to move. Accelerating charge carriers sooner or later run into atoms within the structure of the wire giving up their kinetic energy in the process (having given up their kinetic energy and bounced off the fixed atomic/molecular structure, they begin to accelerate again in the field). Depending upon how much energy is involved in the collisions, the absorbed energy does one of two things. It either goes into making the molecular structure of the wire vibrate more than usual (this shows itself as *heating up*) or into making the electrons in the atomic structure change energy states (they usually go from their low energy ground state to higher energy states), then cascade back down to their ground level. As they cascade down from state to state, they give off bundles of energy equal to the energy difference between the states. If the energy bundles are the right size, your eyes register them as light.

13.11) For the circuit shown to the right:



a.) How many nodes exist in the circuit?

Solution: Nodes are not corners. Nodes are junctions. They are places where current splits. In this circuit, there are *four* nodes.

b.) How many branches exist in the circuit?

Solution: A branch is a section in which the current is the same everywhere. Branches are ALWAYS bounded by *nodes*. Including the section that includes V_1, there are *six* branches in this circuit.

c.) How many loops exist in the circuit?

Solution: A loop is any path that ends where it started. There are *seven* loops in this circuit. See if you can identify all of them.

d.) How many equations would a rookie need to determine the current being drawn from the power supply V_1?

Solution: There are six branches. Each branch must have a current assigned to it. That means you will have *six* unknown currents to deal with. That will require six equations.

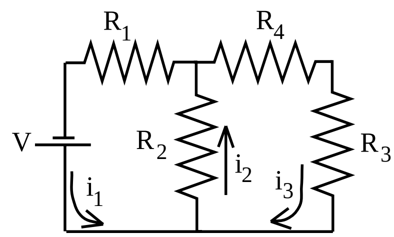
e.) What clever thing could you do that would halve the number of equations identified in *Part d*?

Solution: If you use *node equations* while you are defining each branch's current, you will be able to whittle the required number of *loop equations* down to *three*.

f.) There are two constraints placed on the equations you would need to solve for the current drawn from the power supply V_1. What are these constraints?

Solution: Constraint #1: You must use both node and loop equations when you begin your analysis. You *can't* do it all with, say, just loop equations. Why? Because they won't all be independent and, when solved simultaneously, will give you current values equal to zero. Constraint #2: All of the power supplies must be represented in at least one of the loop equations. Even though you might be able to come up with enough loop equations without including a loop in which one of the power sources exists, failing to include all the power supplies at least somewhere will yield bogus results.

13.12) Consider the circuit shown to the right.



a.) How many nodes are there in this circuit?

Solution: There are only *two* nodes in the circuit. Again, nodes aren't corners, they are junctions.

b.) How many independent node equations can you write for this circuit?

Solution: There is one independent node equation. If you use the second node, you will end up with the same relationship you got from the first equation. Specifically, determining the *current in* and *current out* for the bottom node yields $i_1 + i_3 = i_2$. Doing the same for the top node yields $i_2 = i_1 + i_3$. You will never have as many independent node equations as you have nodes.

c.) Why would you expect the number in *Part a* and the number in *Part b* to be different?

Solution: This was answered in *Part 13.12b*.

d.) There are three loops available in the circuit. If you wrote out loop equations for all three loops and tried to solve them simultaneously for the current i_2, you would get *zero* as a result. This makes no sense. What's wrong? That is, why are you calculating *zero current* in a section you *know* has current flowing through it?

Solution: There are three loops, which means you *could* write out three loop equations. The problem is that only *two* of those equations would be independent. That is, take any two and combine them and you will get the third equation. You need three independent equations to solve for three unknowns, but because you only have two of them wrapped up in your three loop equations, the math will register that oversight by yielding *zero* as the solution to all current values (that is why you will, in addition to the two loop equations you choose to use, need to write out a node equation to complete the set).

e.) Are R_1 and R_2 in series? Justify.

Solution: For resistors to be in series, they must have the same current passing through them. You can't have a node (a junction) in the middle of a series combination because if you did, current would split up with some going along one branch and some going along the other. In doing so, all the elements would no longer have the same current.

f.) Are there *any* series combinations in the circuit?

Solution: R_3 and R_4 are in series.

g.) Are there *any* parallel combinations in the circuit?

Solution: There are no single resistors in parallel with one another, but R_2 is in parallel with the series combination of R_3 and R_4.

h.) Is there anything wrong with the circuit as it is set up? That is, have I forgotten and/or mislabeled anything? Explain.

Solution: The temptation might be to assume that because there seems to be a current i_3 associated with R_3, there should be a current i_4 associated with R_4. This is wrong. The current i_3 passes through both R_3 and R_4. Including a separate current variable for R_4 will only confuse you down the line and make the problem a whole lot harder than it needs to be.

i.) Assume all the resistors have the same resistance, say, 10 ohms, except R_4, which is twice as large. Assume you don't know V, but you do know the voltage across R_2 is 60 volts. What is the *easiest* way to determine the voltage across R_4? In fact, for the humor of it, do that calculation.

Solution: Being in series, the current through R_3 and R_4 is the same. As R_4 is twice as big as R_3, it will have twice the voltage drop across it ($V_3 = iR$ versus $V_4 = i(2R)$). That means that if we knew the total voltage drop across the R_3/R_4 series combination, two-thirds of the drop would be across R_4, and one-third would be across R_3. But we know the total voltage across R_3 and R_4 because R_2 is in parallel with the R_3/R_4 series combination, and we know the voltage drop across R_2 is 60 volts. In short, the drop across R_4 will be *(2/3)(60 volts) = 40 volts*.

13.13) The system of units generally in use in the U.S. is called *the English system of units*. What that means is that you grew up using measures like pounds, feet and inches as your standards. There are two units of measure in the world of electrical systems that you have grown up with that aren't a part of the English system of units. What are they?

Solution: The *volt* is the MKS unit for *joules/Coulomb* (i.e., for potential energy per unit charge) and the *watt* is the MKS unit for *joules/second* (i.e., for power).

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

Solution: The power dissipated by a resistor is equal to i^2R, where i is the current through the resistor and R is the resistance of the resistor. Doubling the current will increase the power dissipated by a factor of $2^2 = 4$.

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?

Solution: This is a little bit trickier. When the resistance goes down in a circuit, the current goes up proportionally. That means that halving the resistance will double the current. Power is governed not by resistance and current but by resistance and current *squared*. The net effect of halving the resistance, hence doubling the current, will be to double the power dissipated (that is, $P = (2i)^2(R/2) = 2i^2R$).

13.16) You have a resistor attached to a power supply. You halve the voltage of the ideal power supply.

a.) How will that affect the power being provided by the power supply?

Solution: Halving the voltage will halve the current. The power being provided by a power supply is equal to iV, where i is the current drawn from the power supply and V is the voltage across the power supply. Halving the voltage, which halves the current, will produce a power cut equal to $1/4$ of the original power.

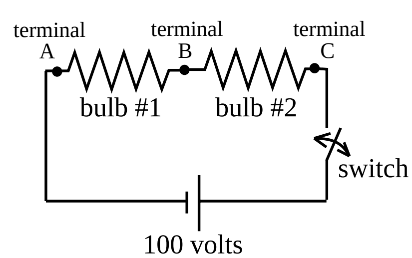
b.) How will that affect the power being dissipated by the resistor?

Solution: If the power being provided to the circuit is quartered, the power dissipated by the resistor must also be quartered (this shouldn't be a surprise--ignoring minor energy loss to wires heating up, etc., all the energy provided by the power supply will be dissipated by the resistor--if the power to the circuit goes down, the power dissipated by the resistor must also go down by the same amount). Mathematically, the power dissipated by a resistor is proportional to i^2 (i.e., $P = i^2R$), if the current is halved the power should diminish to $(1/2)^2 = 1/4$.

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?

Solution: The 20 watt bulb needs to dissipate more power to operate properly. Because power in a resistor is governed by the current (i.e., $P = i^2R$), you need a large current to make this happen. To get a large current, you need low resistance. Bottom line: the 20 watt light bulb should have the lower resistance.

13.18) Two light bulbs are hooked in series to an ideal power supply (assume the resistance of a light bulb is *not* temperature dependent).



a.) *Bulb #1* is taken out of the circuit by putting a wire across terminals A and B. The switch is closed, and it is observed that *bulb #2* dissipates 40 watts of power.

i.) How much current is being drawn from the power supply in this situation?

Solution: With *bulb 1* out of the circuit, the entire 100 volts is across *bulb 2*. The power dissipated by the resistance of the bulb in this case will be iV, so *(40 watts) = i(100 volts)*. Solving yields $i = .4$ *amps*.

ii.) What is the resistance of *bulb #2*?

Solution: We can do this in one of two ways. Using the power relationship $P = i^2R$, we can write $(40 \text{ watts}) = (.4 \text{ amps})^2R$, or $R = 250$ *ohms*. The other way is to use Ohm's Law. In that case, $V = iR$ becomes $(100 \text{ volts}) = (.4 \text{ amps})R$, or $R = 250$ *ohms*.

b.) Removing the wire across terminals *A* and *B* and placing it across terminals *B* and *C*. The switch is closed, and it is observed that *bulb #1* dissipates 10 watts of power.

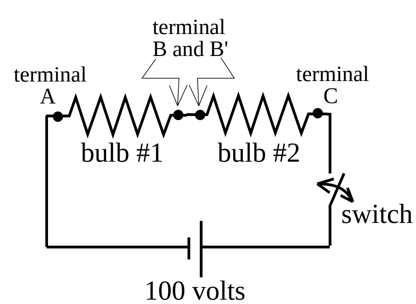
i.) How much current is being drawn from the power supply in this situation?

Solution: With *bulb 2* out of the circuit, the entire 100 volts is across *bulb 1*. The power dissipated by the resistance of the bulb in this case will be iV, so *(10 watts) = i(100 volts)*. Solving yields $i = .1$ *amps*.

ii.) What is the resistance of *bulb #1*?

Solution: We can do this in one of two ways. Using the power relationship $P = i^2R$, we can write $(10 \text{ watts}) = (.1 \text{ amps})^2R$, or $R = 1000$ *ohms*. The other way is to use Ohm's Law. In that case, $V = iR$ becomes $(100 \text{ volts}) = (.1 \text{ amps})R$, or $R = 1000$ *ohms*.

c.) Both bulbs are placed in series across the power supply and the switch is closed.



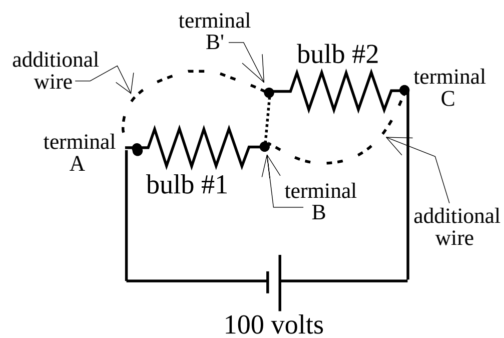
i.) What is the current in this circuit?

Solution: You now have two resistors in series. Their equivalent resistance is 1250 ohms. Using Ohm's Law ($V = iR_{equiv}$) we get $(100 \text{ volts}) = i(1250 \text{ ohms})$, or $i = .08$ *amps*.

ii.) What will happen in the circuit? That is, will both bulbs light up? If not, which one won't . . . and why won't it?

Solution: This is a little bit tricky, but kinda interesting. The 40 watt bulb requires .4 amps to operate appropriately. With the two bulbs in series, though, you only get .08 amps flowing in the circuit. That means the 40 watt bulb won't light. Current will flow through it, but there won't be enough energy in the flow to light up the bulb. The 10 watt bulb requires .1 amps to operate correctly. With the series current of .08 amps, it will light up but not as brightly as it would in the optimal case. What you'd have, in other words, would be one bulb that was dark and another that was dimly lit.

d.) Using the terminals available in the sketch, can you add lines (i.e., wires) to make the original bulb configuration into a parallel combination without disconnecting any of the wires already there? If you can, draw the circuit. If you can't, explain what's stopping you.



Solution: This can't be done if disconnecting wires is verboten. To see this, look at the sketches (I've modified things a bit to make things clearer). Note that *terminal B* has been split into *terminals B* and *B'*. They are essentially the same points, but to be able to visualize a parallel combination, I needed to be able to move *bulb #2* upward a bit. I've connected the two by a dotted line and added two more wires. *If the dotted line didn't exist within the circuit*, we would have our parallel combination. Unfortunately, the dotted line can't be removed because it depicts a connection between two points that are supposed to be one. As long as those two terminals are connected, the extra wires will do nothing more than short the bulbs. Only by disconnecting *B* and *B'* can we create a parallel combination.

e.) Let's say you did whatever was appropriate to make the bulb configuration into a parallel combination.

i.) How will the current in the circuit change from what it was as a series combination? Think about this conceptually before trying to do it mathematically.

Solution: According to *Parts 18a-ii* and *b-ii*, the resistance of *bulb #1* is $1000\,\Omega$ and *bulb #2* is $250\,\Omega$. The equivalent resistance of the series combination is, therefore, $1250\,\Omega$. It was determined in *Part 18c-ii* that the current in the series situations was .08 amps. If we put the resistors in parallel, their equivalent resistance will be $[(1/250) + (1/1000)]^{-1} = 200\ \Omega$. With the net resistance going down, the net current will go up. In fact, because the voltage will be the same in each case, the new current will be (1250/200)(.08) = .5 amps. (For those of you who are mystified as to how this expression came about, $V = i_{series}R_{eq,\,series} = i_{parallel}R_{eq,parallel}$.)

ii.) Is more power dissipated in the series or the parallel combination? Again, think about this conceptually.

Solution: Power is governed by current. The combination that draws the greatest current will dissipate the most power. In this case, the parallel circuit takes the cake.

iii.) What is the ratio of power between the two kinds of circuits?

Solution: For the parallel combination, $P = i_p^{\,2}R_{eq,p} = (.1004\ A)^2(996\,\Omega) = 10.04$ *watts*. For the series combination, $P = i_s^{\,2}R_{eq,s} = (.08A)^2(1250\,\Omega) = 8.0$ *watts*. The ratio of the two is $P_s/P_p = 8/10.04 = .8$.

13.19) Consider Figure I:

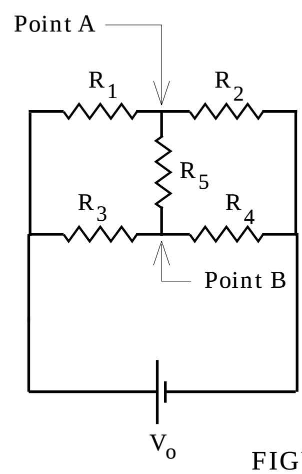


FIGURE I

a.) If no current is to flow through R_5, what must be true?

Solution: The voltage drop across R_5 must be zero if there is to be no current through it, which means the voltage of *Points A* and *B* on the sketch must be identical.

b.) If $V_A = 3.36$ *volts* and $V_B = 5.25$ *volts* (*Points A* and *B* are defined in the sketch to the right), in which direction will current flow through R_5?

Solution: Current flow is defined as the direction in which *positive* charge carriers travel (assume positive charges *could* move through a circuit). That means current flows from the higher *absolute electrical potential* (*Point B* at $V_B = 5.25$ *volts*) to the lower *absolute electrical potential* (*Point A* at $V_A = 3.36$ *volts*).

c.) Given the situation outlined in *Part b* and assuming $R_5 = 3$ *ohms*, what is the current through R_5?

Solution: Assuming $R_5 = 3\ \Omega$, the current through R_5 will be:

$$V_5 = i_5R_5,$$

where V_5 is the voltage drop across R_5 (i.e., 5.25 volts - 3.36 volts = 1.89 volts).

NOTE: This voltage value should be properly called DV_5 as it denotes a *voltage difference* between the two sides of a resistor. It isn't denoted that way because physicists have become lazy with their notation. This book will go with the convention. You need to realize that when you see a V term in a circuit expression, the V is not denoting an *electrical potential* at a particular point but rather an *electrical potential difference* between two points.

Putting in the values yields:

$$V_5 = i_5 R_5$$
$$1.89 = i_5\ (3\ \Omega)$$
$$\Rightarrow \quad i_5 = .63 \text{ amps.}$$

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

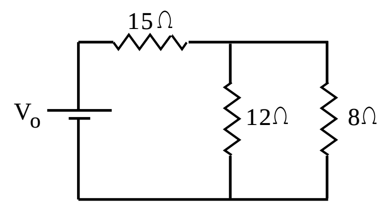


FIGURE II

a.) What is the current through the 8 Ω resistor?

Solution: The voltage across the 12 ohm resistor is the same as the voltage across the 8 ohm resistor. That means that

$$(12 \text{ ohms})(.5\text{ A}) = (8 \text{ ohms})i,$$

or

$$i = .75 \text{ amps.}$$

b.) What is the power supply's voltage?

Solution: The total current being drawn from the power supply is equal to the .5 amps through the 12 ohm resistor and the .75 amps through the 8 ohm resistor, or 1.25 amps. The voltage across the power supply is the same as the voltage across the 15 ohm resistor added to the voltage across the 12 ohm resistor (or, if you'd prefer, across the 8 ohm resistor--that number will be the same). Doing the math yields

$$\begin{aligned} V &= (15 \text{ ohms})(1.25\text{ A}) + (12 \text{ ohms})(.5\text{ A}) \\ &= 24.75 \text{ volts.} \end{aligned}$$

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

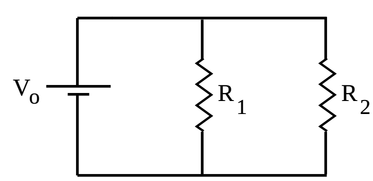


FIGURE III

a.) R_2's voltage;

Solution: The voltage across R_2 is held constant by the battery. Decreasing the size of the resistor does nothing to the *voltage* across the resistor.

b.) R_2's current;

Solution: Ohm's Law says the voltage across a resistor and the current through the resistor are related as $V_r = iR$. If V_r remains the same and R *decreases*, i must *increase.*

c.) R_1's voltage;

Solution: The voltage across R_1 is held at V_o by the battery, therefore fooling around with R_2 will do nothing to R_1*'s voltage* or *current.*

d.) the power dissipated by R_2?

Solution: The power dissipated by any resistor is equal to i^2R. If R decreases by, say, a factor of two (i.e., it halves), the current will go up by a factor of two (see *Part b* for the rationale). As power is a function of current *squared* while only being a linear function of resistance, halving the resistance while doubling the current will increase the power by a factor of two. Doing this mathematically, we get:

$$\begin{aligned} P_{old} &= i^2R \\ P_{new} &= (2i)^2(R/2) \\ &= (4i^2)(R/2) \\ &= 2i^2R = 2P_{old}. \end{aligned}$$

13.22) In Figure IV, all the resistors are the same and all the ideal power sources are the same. If the current in the series circuit is .4 amps, what is the current drawn from V_o in the parallel circuit?

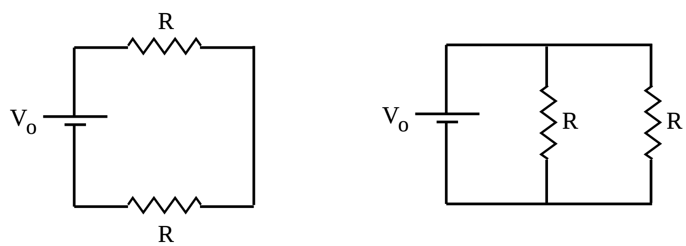


FIGURE IV

Solution: This is a "use your head" problem. For the series circuit, we calculate the battery voltage as:

$$\begin{aligned} V_o &= iR_{eq} \\ &= i(R + R) \\ &= (.4\text{ a})(2R) \\ &= .8R. \end{aligned}$$

For the parallel circuit, the battery voltage V_o (.8R as calculated above) is the same as the voltage across each resistor (resistors in parallel have the same voltage across them). Using Ohm's Law on each of those resistors yields:

$$V_o = i_1R.$$

Putting in the voltage V_o yields:

$$\begin{aligned} .8R &= i_1R \\ \Rightarrow \quad i_1 &= .8\text{ amps}. \end{aligned}$$

As R is the same in both parallel branches, .8 amps is drawn through both branches making the total current drawn from the battery 1.6 amps.

13.23) Resistors $R_1 = 10\ \Omega$, $R_2 = 12\ \Omega$, and $R_3 = 16\ \Omega$ are connected in parallel. If the current through the 12 Ω resistor is 2 amps, determine the currents through the other two resistors.

Solution: Knowing the current and resistance involved in one of the single-resistor branches allows us to determine the voltage across each branch (by definition, the voltage across any one branch of a parallel combination will equal the voltage across any other branch). As such:

$$
\begin{aligned}
V &= i_2R_2 \\
&= (2\text{ a})(12\ \Omega) \\
&= 24\text{ volts.}
\end{aligned}
$$

--For $R_1 = 10\ \Omega$:

$$
\begin{aligned}
V &= i_1R_1 \\
\Rightarrow \quad i_1 &= V/R_1 \\
&= (24\text{ v})/(10\ \Omega) \\
&= 2.4\text{ amps.}
\end{aligned}
$$

--For $R_3 = 16\ \Omega$:

$$
\begin{aligned}
V &= i_3R_3 \\
\Rightarrow \quad i_3 &= V/R_3 \\
&= (24\text{ v})/(16\ \Omega) \\
&= 1.5\text{ amps.}
\end{aligned}
$$

13.24) A battery charger delivers 6 amps of current to a 45 Ω resistor for 30 minutes.

Note: Whenever time is incorporated into a problem, there is a good chance you will either be working with power (work/unit time) or current (charge passing a point/unit time). In this case, it is both.

a.) How much charge passes through the resistor?

Solution: The definition of current is *q/t*, where *q* is the *total charge passing by a point* in the circuit *during a time interval t*. Noting that time must be in seconds and using the current definition yields:

$$
\begin{aligned}
i &= q/t \\
\Rightarrow \quad q &= it \\
&= (6\text{ a})[(30\text{ min})(60\text{ sec/min})] \\
&= 10{,}800\text{ coulombs.}
\end{aligned}
$$

b.) How much work does the charger do?

Solution: In terms of electrical parameters, the electrical potential difference (i.e., $\Delta V = V$) between two points equals the work/charge available to any charge that moves between the points. As such:

$$W = qV.$$

As the *voltage difference* across a resistor is $V = ir$, we can write:

$$W = q(ir)$$

$$= (10{,}800\ \text{C})\left[(6\ \text{amps})(45\ \Omega)\right]$$
$$= 2.9\text{x}10^6\ \text{joules.}$$

c.) How much power does the charger deliver?

Solution: Power is formally defined as the *work per unit time* done on or by a system. Using that definition yields:

$$\begin{aligned} P &= W/t \\ &= (2.9\text{x}10^6\ \text{joules})/[(30\ \text{min})(60\ \text{sec/min})] \\ &= 1.6\text{x}10^3\ \text{watts.} \end{aligned}$$

13.25) A power supply provides 125 watts to an 18 Ω resistor.

Note: The power provided to the 18 Ω resistor is 125 watts. That means the resistor can (and does) dissipate 125 joules of energy per second (watts are joules/second).

a.) Determine the current through the resistor.

Solution: Using the definition of power, we get:

$$\begin{aligned} P &= i^2R \\ \Rightarrow \quad i &= (P/R)^{1/2} \\ &= [(125\ \text{w})/(18\ \Omega)]^{1/2} \\ &= 2.64\ \text{amps.} \end{aligned}$$

b.) Determine the voltage across the resistor.

Solution: The voltage across a resistor through which the current is known is determined using Ohm's Law. That is:

$$\begin{aligned} V &= iR \\ &= (2.64\ \text{a})(18\ \Omega) \\ &= 47.52\ \text{volts.} \end{aligned}$$

Note: $P = iV = (47.52\ \text{volts})(2.64\ \text{amps}) = 125.45\ \text{watts}$ . . . close enough!

13.26) Assuming all resistors available are 5 Ω, determine the equivalent resistance of the circuits found in Figure V.

Solution: For *a*, we get 5 ohms (that was easy). For the rest, each is untangled below with successive steps shown.

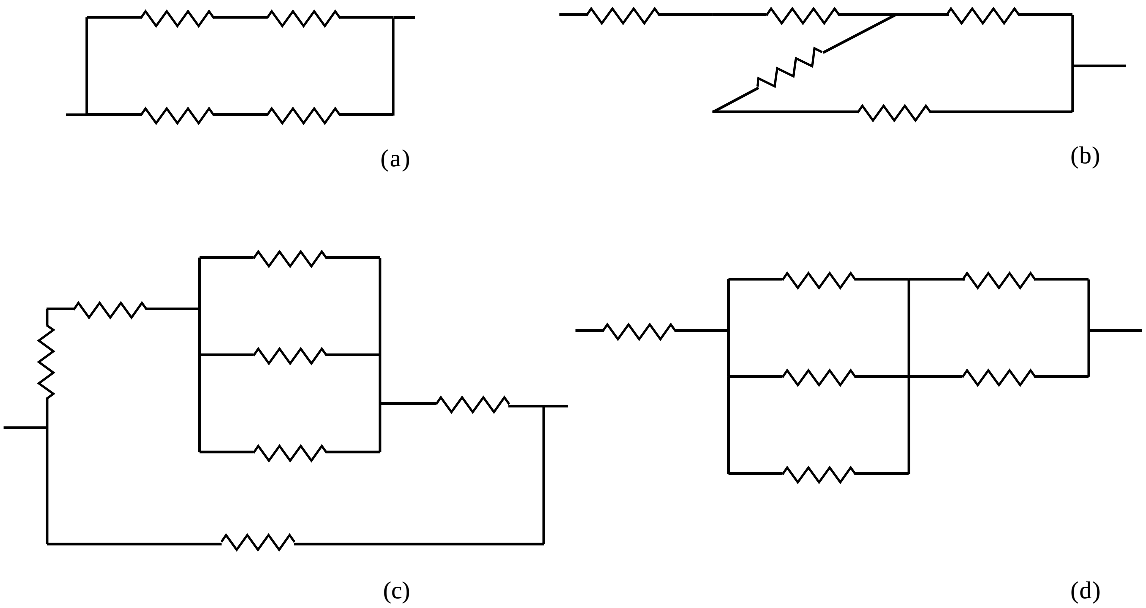
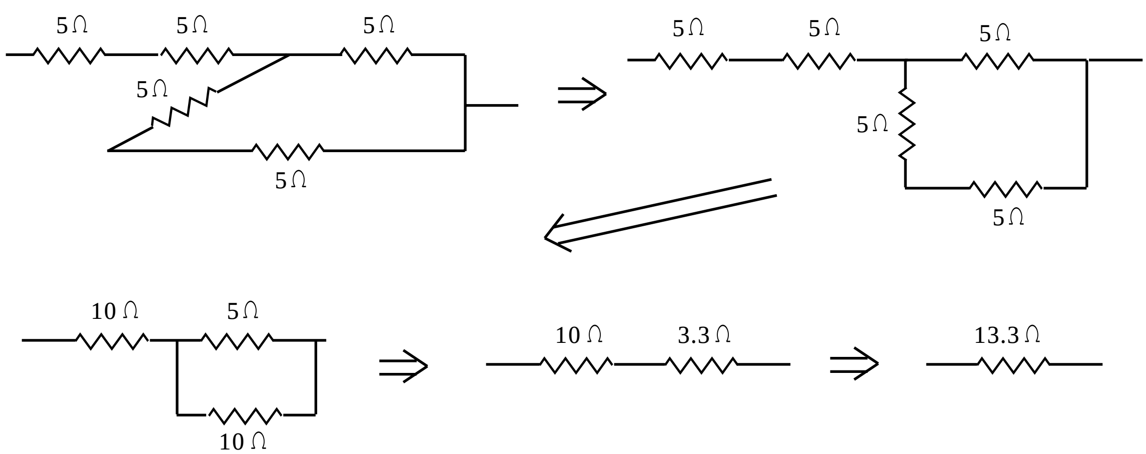


FIGURE V

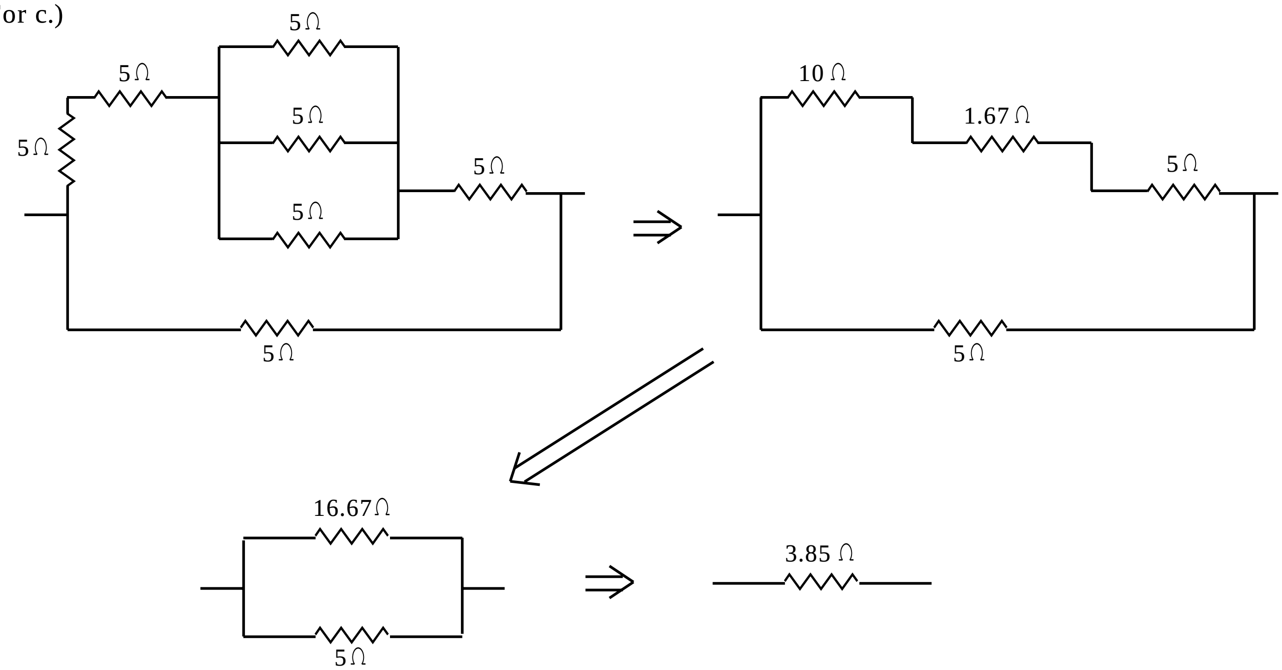
Solution:

For a.), we just have two five ohm resistors in series (this gives us a net of 10 ohms) twice and in parallel. That leaves us with a net of 5 ohms.

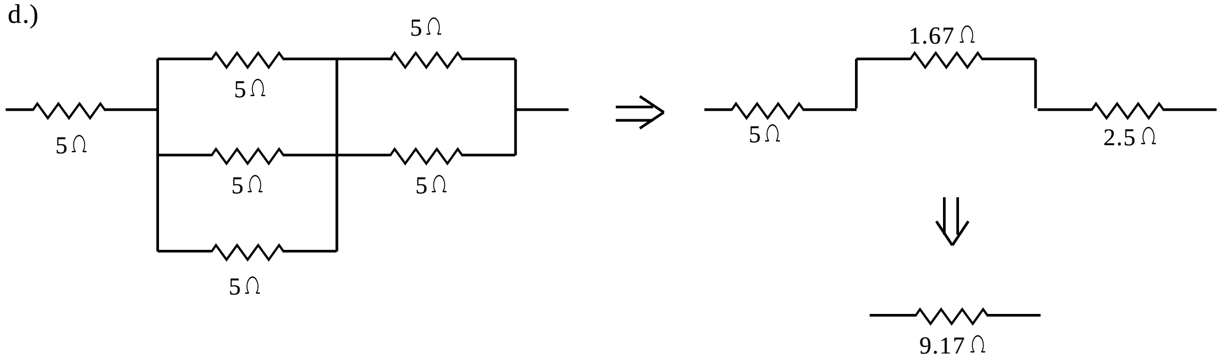
For b.)



For c.)



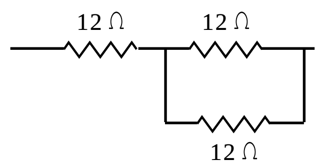
For d.)



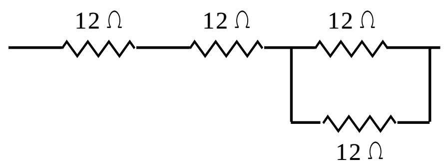
13.27) Using as many 12 Ω resistors as you need, produce a resistor circuit whose equivalent resistance is:

Solution: Doing problems like this, the best way to start is to use a *series combination* to get close to the required value, then use *series* and *parallel combinations* as need be to zero in on the actual value desired.

a.) 18 Ω:



b.) 30 Ω:



13.28) The ideal power dissipated by the circuit in Figure VI is 800 watts. What is *R*?

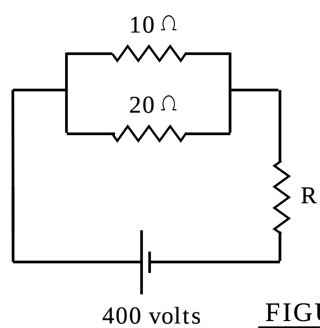


FIGURE VI

Solution: We can determine the total current drawn from the battery knowing that the power provided by the battery is 800 watts and the voltage of the battery is 400 volts. Doing so yields:

$$P_{bat} = i_{tot}V_{bat}$$
$$\Rightarrow \quad i_{tot} = P_{bat}/V_{bat}$$
$$= (800 \text{ w})/(400 \text{ v})$$
$$= 2 \text{ amps.}$$

The equivalent resistance of the parallel combination is:

$$1/R_{equ} = 1/(10\ \Omega) + 1/(20\ \Omega)$$
$$\Rightarrow \quad R_{equ} = 6.67\ \Omega.$$

The total equivalent resistance of the parallel resistor combination in series with *R* is:

$$R_{eq,tot} = R + 6.67\ \Omega.$$

The total voltage across all the resistors (equal to the battery's voltage) equals the total current through the system times the total equivalent resistance of the system ($R_{eq,tot}$), or:

$$V_{bat} = i_{tot}\ R_{eq,tot}$$
$$(400 \text{ v}) = (2 \text{ a})(R + 6.67\ \Omega)$$
$$\Rightarrow \quad R = 193.3\ \Omega.$$

13.29) Examine Figure VII:

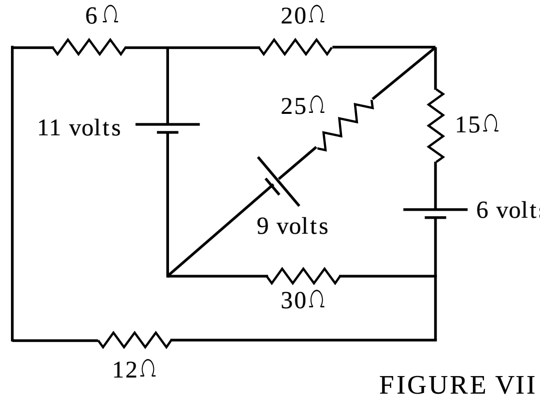


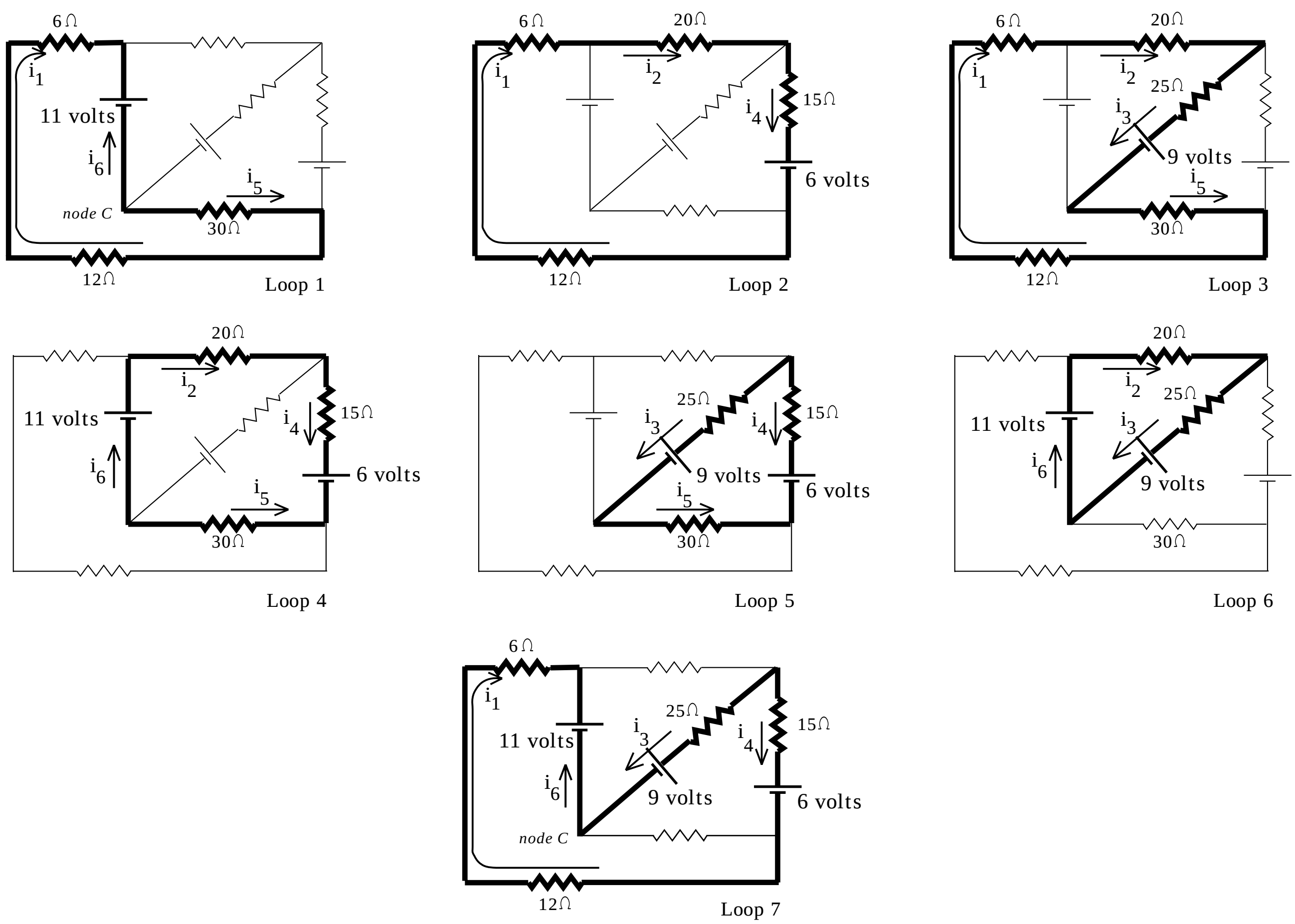
FIGURE VII

a.) How many nodes are there in the circuit?

Solution: There are four nodes in this circuit (look at Figure VII to the right).

b.) How many loops?

Solution: There are *seven loops* in this circuit. Each has been highlighted in the composite Figures shown below. Note that although you don't have to include current directions when defining loops, the current information is needed when writing out *loop equations*. As such, relevant currents have been included in the diagrams while extraneous information has been deleted.



c.) Write out any three *node equations* using the information provided in the circuit.

Solution: The possible *node equations* are:

Node A: $i_1 + i_6 = i_2$;
Node B: $i_2 = i_3 + i_4$;
Node C: $i_3 = i_6 + i_5$;
Node D: $i_4 + i_5 = i_1$.

d.) Write out any three *loop equations*.

Solution: The possible *loop equations* are shown below. Note that in all cases, I have arbitrarily chosen to traverse the loop in a CLOCKWISE direction. Note also that I have included the units for the resistors--something you would probably not bother to do on a test.

Loop 1:
$$-(6\ \Omega)i_1 - (11\text{ volts}) - (30\ \Omega)i_5 - (12\ \Omega)i_1 = 0$$

Loop 2:
$$-(6\ \Omega)i_1 - (20\ \Omega)i_2 - (15\ \Omega)i_4 - (6\text{ volts}) - (12\ \Omega)i_1 = 0$$

Loop 3:
$$-(6\ \Omega)i_1 - (20\ \Omega)i_2 - (25\ \Omega)i_3 - (9\text{ volts}) - (30\ \Omega)i_5 - (12\ \Omega)i_1 = 0$$

Loop 4:
$$-(20\ \Omega)i_2 - (15\ \Omega)i_4 - (6\text{ volts}) + (30\ \Omega)i_5 + (11\text{ volts}) = 0$$

Loop 5:
$$(9\text{ volts}) + (25\ \Omega)i_3 - (15\ \Omega)i_4 - (6\text{ volts}) + (30\ \Omega)i_5 = 0$$

Loop 6:
$$(11\text{ volts}) - (20\ \Omega)i_2 - (25\ \Omega)i_3 - (9\text{ volts}) = 0$$

Loop 7:
$$-(6\ \Omega)i_1 - (11\text{ volts}) + (9\text{ volts}) + (25\ \Omega)i_3 - (15\ \Omega)i_4 - (6\text{ volts}) - (12\ \Omega)i_1 = 0$$

13.30) Use Kirchoff's Laws to determine the meter readings in the circuits shown in Figure VIII.

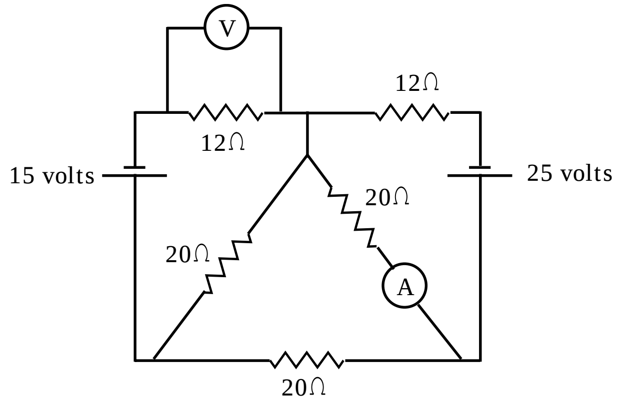
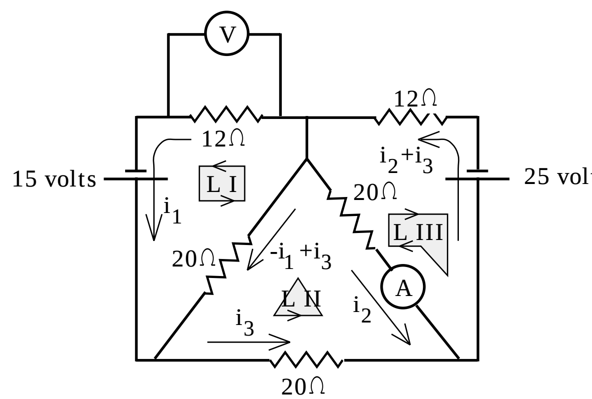


FIGURE VIII

Note 1: There are *five primary branches* in the circuit (primary branches do not include *voltmeter branches*). That means you are either going to have to analyze a 5x5 matrix or be clever in the way you define your currents. My suggestion: be clever. Begin by defining a current or two, then use your node equations to define all the other currents in terms of the first few. In doing so, you should be able to whittle the number of variables down considerably (or, at least, by one).

Solution: The circuit along with loops and currents is shown to the right. Notice that the currents we need are defined as i_1 and i_2. The loop equations follow.



Loop I:

$$(15 \text{ volts}) + (20\ \Omega)(-i_1 + i_3) - (12\ \Omega)i_1 = 0$$

fi $\quad 32i_1 - 20i_3 = 15$ (Equation A).

Loop II:

$$-(20\ \Omega)(-i_1 + i_3) - (20\ \Omega)i_3 + 20i_2 = 0$$

fi $\quad 20i_1 + 20i_2 - 40i_3 = 0$ (Equation B).

Loop III:

$$(25 \text{ volts}) + (20\ \Omega)i_2 + (12\ \Omega)(i_2 + i_3) = 0$$

fi $\quad 32i_2 + 12i_3 = -25$ (Equation C).

These are put in DETERMINATE matrix form as shown to the right:

$$\begin{vmatrix} 32 & 0 & -20 \\ 20 & 20 & -40 \\ 0 & 32 & 12 \end{vmatrix} = \begin{vmatrix} 15 \\ 0 \\ -25 \end{vmatrix}$$

Solving for i_1 yields:

$$i_1 = \frac{D_{mod,i_1}}{D} = \frac{\begin{vmatrix} 15 & 0 & -20 \\ 0 & 20 & -40 \\ -25 & 32 & 12 \end{vmatrix}}{\begin{vmatrix} 32 & 0 & -20 \\ 20 & 20 & -40 \\ 0 & 32 & 12 \end{vmatrix}}$$

$$i_1 = \frac{\big[(15)[240 - (-1280)] + [0] + (-20)[(0) - (-500)]\big]}{\big[(32)[240 - (-1280)] + [0] + (-20)[(640) - (0)]\big]}$$

$= .357$ amps.

Solving for i_2 yields:

$$i_2 = \frac{D_{mod,i_2}}{D} = \frac{\begin{vmatrix} 32 & 15 & -20 \\ 20 & 0 & -40 \\ 0 & -25 & 12 \end{vmatrix}}{\begin{vmatrix} 32 & 0 & -20 \\ 20 & 20 & -40 \\ 0 & 32 & 12 \end{vmatrix}}$$

$$i_2 = \frac{\big[(32)[0 - (1000)] + (15)[(0) - (240)] + (-20)[(-500) - (0)]\big]}{\big[(32)[240 - (-1280)] + [0] + (-20)[(640) - (0)]\big]}$$

$= -.714$ amps.

We now know:

--the current through the ammeter A is $i_2 = -.714$ *amps*;

--the voltmeter will read $i_1 R_{12\Omega} = (.357\ A)(12\ \Omega) = 4.29$ *volts*.

13.31) Charge carriers in a DC circuit move in one direction only. What do charge carriers do in an AC circuit?

Solution: Because AC power supply produces an electric potential difference that alternates in direction, the electric field produced by it will also alternate back and forth. With this kind of force field happening, charge carriers will jiggle back and forth.

13.32) The idea of *current through* and *voltage across* a resistor in a DC circuit is fairly straightforward. Current measures the amount of charge that passes through the resistor *per unit time*, and voltage measures the unchanging voltage difference between the two sides of the resistor. The idea of a resistor's current and voltage in an AC circuit is a little more complex, given the fact that the charge carriers in AC circuits don't really go anywhere. So how do we deal with the idea of current and voltage in an AC circuit? That is, when someone says that your home wall socket is providing 110 volts AC, and that a light bulb plugged into that socket draws .2 amps of current, what are those numbers really telling you?

Solution: The key is *power*. An AC power supply will provide AC current that will provide a certain amount of net power to a circuit. It is possible to make a DC power supply provide just the right amount of current so that it matches that power output. This "DC equivalent" voltage and current is called the *RMS voltage* and the *RMS current* (the letters *RMS* stand for "root mean square," which is exactly the process you have to go through to get this quantity), and the two values are how AC circuits are rated (i.e., those values are the values that AC ammeters and voltmeters read). Numerically, the two quantities are equal to .707 of the *amplitude* of the AC parameter being measured. That is, $V_{RMS} = .707V_o$, and $i_{RMS} = .707i_o$, where V_o and i_o are the MAXIMUM voltage and current values (that is, the amplitudes of the voltage and current functions).

13.33) An AC voltage source is found to produce a 12 volt peak to peak signal at 2500 hertz.

a.) Characterize this voltage as a *sine function*.

Solution: A *peak to peak* voltage is equal to twice the amplitude of the function, so $V_o = 6\ volts$. The frequency is $\nu = 2500\ hertz$, so the sine's argument, $2\pi\nu = 2\pi(2500\ hertz) = 15700$ yields a time dependent voltage function of $V(t) = V_o \sin(2\pi\nu)t = 6 \sin 15700\ t$.

b.) Graph the *voltage versus time* function.

Solution: Oh, hell, you know what a sine wave looks like.

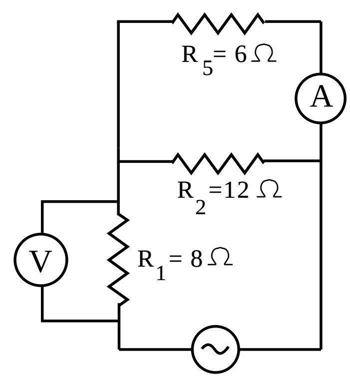
c.) Determine the *RMS voltage* of the source and put that value on your graph from *part b*.

Solution: The *RMS* value will be .707 of the amplitude, or *.707(6) = 4.24 volts*. If you sketch this on the non-exisent graph from *Part b*, it would like a straight line positioned at 4.24 volts.

d.) It is found that an ammeter in the circuit reads 1.2 amps. What is the *maximum current* drawn from the source?

Solution: The maximum current will be the amplitude of the current function. AC ammeters read *RMS* values, so the maximum current through that branch will be $i_o = (1.2\ amps)/(.707) = 1.7\ amps$.

.



13.34) The AC source shown in the circuit provides a voltage equal to 25 sin (300t).

a.) What is the frequency of the source?

Solution: The time coefficient is equal to $2\pi\nu$. That means that $\nu = (300)/(2\pi) = 47.78$ *hertz*.

b.) What will the voltmeter read in the circuit?

Solution: The power supply's *RMS voltage* is $.707V_o = .707(25) = 17.68$ *volts*. The equivalent resistance for the circuit is 12 ohms (you can figure this out using your head), so the *RMS current* being drawn from the power supply is $i_{RMS} = V_{RMS}/R_{eq} = (17.68\ volts)/(12\ ohms) = 1.47\ amps$. The voltmeter will measure the *RMS voltage* across the 8 ohm resistor, but according to Ohm's Law that will be $V_8 = i_{battery}R = (1.47\ amps)(8\ ohms) = 11.76\ volts$.

c.) What will the ammeter read in the circuit?

Solution: Considering the loop that traverses around the outside part of the circuit (i.e., that ignores the 12 ohm resistor), we can track the voltages around that loop. The voltage across the battery is 17.68 volts. The voltage across the 8 ohm resistor is 11.76 volts (that from above). That means the voltage across the 6 ohm resistor has to be *17.68 volts - 11.76 volts = 5.92 volts*. Knowing the voltage across the 6 ohm resistor, the current through that resistor will be *V/R = (5.92 volts)/(6 ohms) = .99 amps*. That is what the ammeter in that part of the circuit will read. It is the *RMS current* through the 6 ohm resistor.

13.35) The circuit shown in *Problem 13.34* is plugged into a wall socket.

a.) What is the frequency of the source?

Solution: The frequency of a wall socket is 60 hertz.

b.) Characterize this voltage as a *sine function*.

Solution: The voltage will be equal to the amplitude of the voltage function times the sine of *2π times the frequency times time*. The RMS value out of a wall socket is 110 volts. The amplitude is, therefore, *(110 volts)/(.707) = 156 volts*. The *time* coefficient is 2π times the frequency, or *2π(60 Hz) = 377*. That means the overall function will be *156 sin (377t)*.

c.) What will the voltmeter read in the circuit?

Solution: Replacing the AC power supply with its DC equivalent (i.e., the RMS value for the voltage), we get a circuit driven by a DC source whose voltage is 110 volts. R_{eq} for the whole circuit is 12 ohms (this from the previous problem), so the current being drawn from the battery is *(110 volts)/(12 ohms) = 9.17 amps*. The voltage across the resistor R_1 is $i_{bat}R_1 = (9.17\ amps)(8\ ohms) = 73.4\ volts$. That is what the voltmeter will read (i.e., that is the RMS voltage across that resistor).

d.) What will the ammeter read in the circuit?

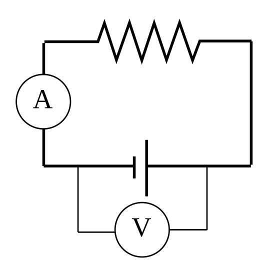
Solution: Considering the loop that traverses around the outside part of the circuit (i.e., that ignores the 12 ohm resistor), we can track the voltages around that loop. The voltage across the battery is 110 volts. The voltage across the 8 ohm resistor is 73.4 volts (that from above). That means the voltage across the 6 ohm resistor has to be *110 volts - 73.4volts = 36.96 volts*. Knowing the voltage across the 6 ohm resistor, the current through that resistor will be $V/R = (36.96\ volts)/(6\ ohms) = 6.16\ amps$. That is what the ammeter in that part of the circuit will read. It is the *RMS current* through the 6 ohm resistor.

13.36) The first voltmeter you used in the circuit shown in *Problem 13.34* didn't register anything. It wasn't broken. What was likely the problem?

Solution: It was probably a DC ammeter. When put in an AC circuit, the needle of a DC ammeter will just sit there or, possibly, slightly quiver.

13.37) I used a transformer to step up the wall-socket voltage (AC) to 5000 volts so that I could charge up a 6000 volt capacitor. After making the voltage into DC (I used a rectifier to do this), I managed to charge the capacitor . . . to the point of blowing it up (well, it didn't blow, but it did die). What went wrong? What was I NOT taking into consideration when I bought the transformer?

Solution: The transformer's rating was RMS. It wasn't telling me the *maximum* voltage I might expect out of the device. The maximum voltage of a device whose RMS rating is 5000 volts is *5000/.707 = 7,072 volts*. A capacitor rated at only 6000 volts isn't going to do very well in this circumstance.



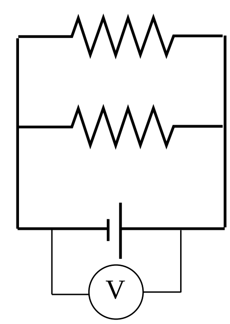
13.38) The theory is simple. Attach a power supply to a resistor. Put a voltmeter across the power supply to measure the supply's voltage and put an ammeter into the circuit measure the current through the resistor. According to Ohm's Law, if you double the voltage, the current should double. So, our hapless teacher takes a light bulb and attaches it to a variable DC power supply (see sketch). She uses the voltmeter to set the power supply voltage (hence the voltage across the bulb) at 40 volts. At this setting the ammeter reads .45 amps. She doubles the voltage to 80 volts expecting to see the current double to .9 amps. What she sees instead is that the current has risen to only .65 amps. So there she sits before a classroom full of students looking like Jacqueline the idiot, with no explanation to be had. Is Ohm's Law working here? Why is the circuit acting the way it is?

<u>Solutions</u>: Ohm's Law states that the voltage across a resistor is directly proportional to the current through the resistor with the proportionality constant being the resistance of the resistor. That proportionality is clearly not happening here. Why not? It turns out that the resistance of a light bulb is dependent upon the temperature of the light bulb. At higher temperature, there is more vibratory motion of the atomic lattice through which charge carriers must flow, so the carriers can't go very far (relatively speaking) without running into something. At a macroscopic level, this translates into *more resistance to current flow*. By similar logic, at low voltage when the current and filament temperature is low, the filament's resistance is fairly low.

The standard is 120 volts across a bulb, so at 40 volts the filament temperature is relatively low. When we double the voltage, the current goes up; the filament temperature goes up; and as a consequence of the increase in temperature, the bulb's net resistance goes up.

In short, increasing the voltage increases the current, but because the resistance has also gone up, the current won't go up as much as we might otherwise expect . . . (hence the current increase in our example to only .65 amps instead of .9 amps).

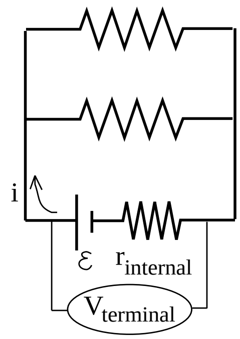
13.39) Once again, the theory is simple. Attach a power supply to two resistors connected in parallel. The voltage across each will be the same and will equal, to a very good approximation, the voltage across the power supply. In theory, nothing will happen to the current through either of the resistors if the other resistors is removed. Why? The voltage will not change across the remaining resistor, so the current should still be V_R/R. So, our hapless teacher (this time a male) takes two light bulbs, hooks them in parallel across a DC power supply, connects a voltmeter across the power supply and uses the meter to set the voltage at 80 volts. He then unscrews one of the light bulbs expecting to find that the brightness of the second bulb does not change. What he finds is that it gets brighter. So there he sits before a classroom full of students looking like Jack the idiot, with no explanation to be had. Is Ohm's Law working here? In any case, why is the circuit acting the way it is?



<u>Solution</u>: The key to this problem lies in the fact that the voltage of the power supply actually went up when the light bulb was unscrewed. How could that be? Answering this will solve our quandry. Unfortunately, understanding this is hindered by the fact that the model we have been using for a power supply is a *simplification* of the real thing.

So first, a little background.

Until now, we have assumed that the voltage difference between the terminals of a power supply (this is called the *terminal voltage*) creates an electric field that motivates charge to flow through an electrical system. That is still true.



where $V_{term} = \mathcal{E} - ir_{int}$

What is usually ignored, at least in ideal, theoretical situations, is that real power supplies have *two* relevent, measureable qualities that need to be taken into account if we are to have an accurate reflection of what the power supply actually, fully does within a circuit.

The first of these qualities has already noted above--the ability to supply energy to the circuit thereby motivating charge to flow. As we've said, power supplies do this by creating an electric field via an electrical potential difference across the supply's terminals.

A true measure of this energy-supplying, charge motivating aspect of the power supply is technically called the supply's *electromotive force*, or EMF (usually characterized by an ε). This name happens to be a misnomer. The quality we are talking about here is not, as the name suggests, a force. It is a measure of the actual electrical potential difference *internally available* within the power supply, and its units are *volts*. Nevertheless, that's what it's called.

What has so-far been ignored is the second current-affecting quality associated with a power supply. That has to do with the power supply's *internal resistance*. This internal resistance also creates a potential difference, but this potential difference is associated with the energy that is *lost* as current flows through the power source.

What this means is that when we use a voltmeter to measure a power supply's *terminal voltage*, what we are really measuring is the energy providing EMF (in volts) *minus* the energy removing voltage drop due to the internal resistance. This is formally expression as $V_{terminal} = \varepsilon - ir_{internal}$.

With all of this in mind, what happened with our parellel circuit?

Once the power supply's EMF is initially set, it remained constant and doesn't change thereafter.

There is a certain amount of resistance wrapped up in the parallel combination of resistors and the internal resistance of the power supply. The power supply's presence generates the appropriate current and all was well.

One resistor is removed.

With one fewer resistors drawing current, the current from the power supply goes down. The EMF doesn't change, but less current means a smaller $ir_{internal}$ drop (if i goes down, ir goes down). That means the terminal voltage $V_{terminal}$ goes UP (look at the expression above--if ε stays the same and $ir_{internal}$ goes down, $V_{terminal}$ goes up).

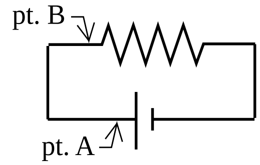
This was why the terminal voltage in our scenario went from 50 volts to 70 volts.

Continuing, an increase in the terminal voltage increases the voltage across the remaining light bulb. That elicits a corresponding increase in current through the light bulb, and the bulb gets brighter.

Finally, if the variable power supply has been manually turned back down to a terminal voltage of 80 volts, the remaining bulb will, as the theory predicts, go back to its original brightness.

Wasn't that fun?

13.40) You hook up the simple circuit shown on the next page. Assume you make the resistance of the resistor really big. You muse about the circuit's inner workings. You realize that an electron leaving the battery has a certain amount of energy. You acknowledge that the voltage at A and the voltage at B are essentially the same, so you accept that only a little bit of the electron's energy will be lost as it moves through the wire. In fact, almost all of its energy will be lost as the electron passes through the resistor. It all makes sense . . . until.



Being perverse, you remove the larger resistor and replace it with a resistor of smaller resistance. You muse. Your guinea pig electron still has the same amount of energy as it leaves the battery, and it still loses the same amount of energy as it passes through the wire, but now it has to get rid of almost all of its energy through a much smaller resistance. How does that work? How can the size of the resistor not matter when it comes to energy loss?

Solution: This is one of those situations where you have to be very careful with the language. When we talk about the *voltage of the battery*, we are referring to the voltage difference between the battery terminals. This quantity tells you how much *work per unit charge* the battery can do on a charge carrier that travels from one terminal to the other. When we refer to *the voltage at point A*, we are referring to the absolute electrical potential at a particular point. This quanity tells us how much *potential energy per unit charge* is available at that point. In short, this question is asking about the potential energy content associated with two individual points.

So consider: When a charge carrier moves from *point A* to *point B*, is there a lot of energy-loss due to its motion?

If the carrier had to move through, say, a large resistor--a circuit element that "burns" energy--there *would* be a large energy loss and the difference in the available *energy per unit charge* between the two points (i.e., the voltage difference between the two points) would be large. If the resistance between *point A* and *point B* was small, then there would be little energy loss and the voltage difference between the two points would essentially be zero.

This last scenario happens to be the case when the only electrical entity between the two points is a wire. Wires have very little resistance to charge flow and, as a consequence, extract very little energy when charge carriers move through them. As such, the voltage at any two points along a wire is, to a very good approximation, the same. In fact, the theory maintains that the points are *exactly* the same voltage-wise, even though that's fudging it a bit.

By definition, an ideal ammeter has no resistance associated with it. That means that, at least in theory, putting an ammeter between *point A* and *point B* should do nothing to the current in the circuit and should not change the electrical potential of *points A* and *B* at all.

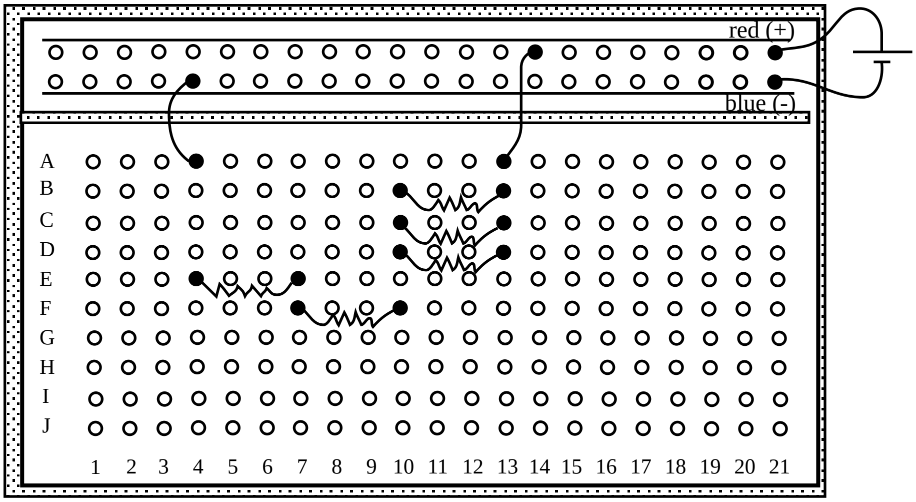
13.41) On the breadboard provided, show the wiring for two resistors and a power supply in series with three resistors in parallel.

Solution: See sketch.

13.42) On the breadboard provided, show the wiring for a power supply in series with three groups of two parallel resistors, all in parallel with a single resistor.

Solution: See sketch.

13.41)


red (+)
blue (-)
A
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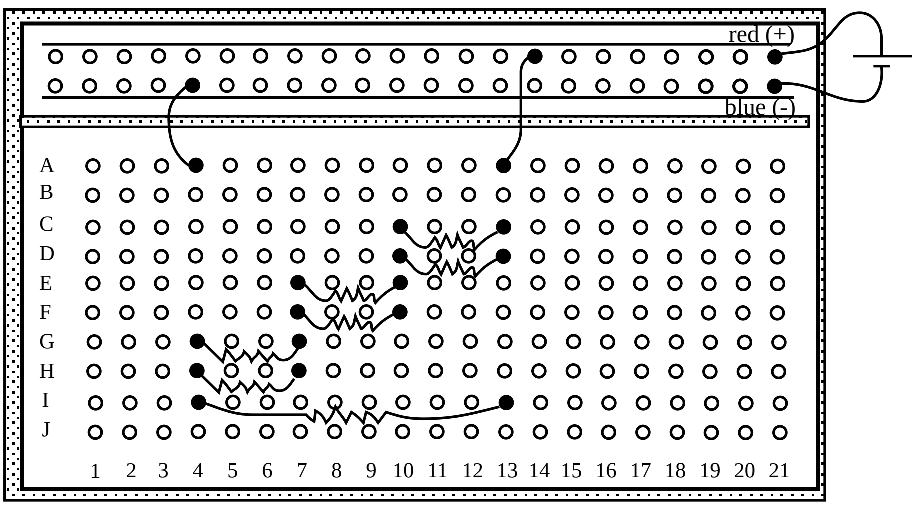
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21

13.42)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