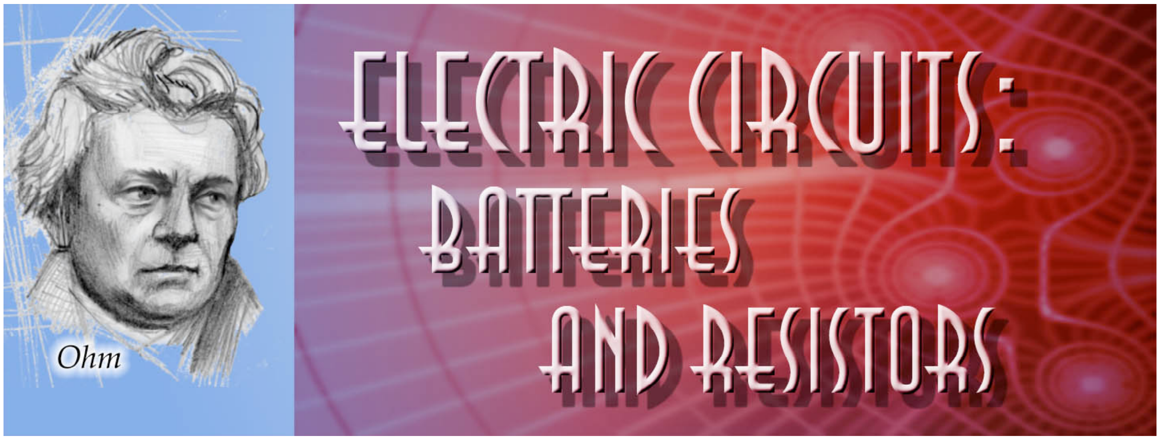


The Big Ideas:

The name *electric current* is given to the phenomenon that occurs when an electric field moves down a wire at close to the speed of light. *Voltage* is the electrical energy density (energy divided by charge) and differences in this density (voltage) cause electric current. *Resistance* is the amount a device in the wire resists the flow of current by converting electrical energy into other forms of energy. A device, the resistor, could be a light bulb, transferring electrical energy into heat and light or an electric motor that converts electric energy into mechanical energy. The difference in energy density across a resistor or other electrical device is called *voltage drop*.

In electric *circuits* (closed loops of wire with resistors and voltage sources) energy must be conserved. It follows that changes in energy density, the algebraic sum of voltage drops and voltage sources, around any closed loop will equal zero.

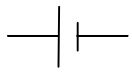
In an electric *junction* there is more than one possible path for current to flow. For charge to be conserved at a junction the current into the junction must equal the current out of the junction.

Key Concepts:

- **Ohm's Law** $V = IR$ (Voltage drop equals current times resistance.)
  This is the main equation for electric circuits but it is often misused. In order to calculate the voltage drop across a light bulb use the formula: $V_{lightbulb} = I_{lightbulb}R_{lightbulb}$. For the *total* current flowing out of the power source, you need the *total* resistance of the circuit and the *total*
  current: $V_{total} = I_{total}R_{total}$.

- **Power** is the rate that energy is released. The units for power are Watts (W), which equal Joules per second [W] = [J]/[s]. Therefore, a 60 W light bulb releases 60 Joules of energy every second.

The equations used to calculate the **power** dissipated in a circuit is $P = IV$. As with Ohm's Law, one must be careful not to mix apples with oranges. If you want the power of the entire circuit, then you multiply the *total* voltage of the power source by the *total* current coming out of the power source. If you want the power dissipated (i.e. released) by a light bulb, then you multiply the *voltage drop* across the light bulb by the *current going through that light bulb*.

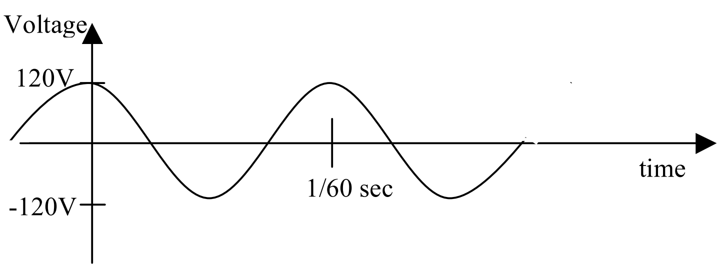
Name	Symbol	Electrical Symbol	Units	Analogy	Everyday device
Voltage	**V**		Volts (V)	A water dam with pipes coming out at different heights. The lower the pipe along the dam wall, the larger the water pressure, thus the higher the voltage.	Battery, the plugs in your house, etc.
Current	**I**		Amps (A) A = C/s	A river of water. Objects connected in series are all on the same river, thus receive the same current. Objects connected in parallel make the main river branch into smaller rivers. These guys all have different currents.	Whatever you plug into your wall sockets draws current
Resistance	**R**		Ohm (Ω)	If current is analogous to a river, then resistance is the amount of rocks in the river. The bigger the resistance the less current that flows	Light bulb, Toaster, etc.

- **Resistors in Series:** All resistors are connected end to end. There is only one river, so they all receive the same current. But since there is a voltage drop across each resistor, they may all have different voltages across them. The more resistors in series the more rocks in the river, so the less current that flows.
  $R_{total} = R_1 + R_2 + R_3 + \ldots$

- **Resistors in Parallel:** All resistors are connected together at both ends. There are many rivers (i.e. The main river branches off into many other rivers), so all resistors receive different amounts of current. But since they are all connected to the same point at both ends they all receive the same voltage.
  $\frac{1}{R_{total}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots$

- **DC Power:** Voltage and current flow in one direction. Examples are batteries and the power supplies we use in class.

- **AC Power:** Voltage and current flow in alternate directions. In the US they reverse direction 60 times a second. (This is a more efficient way to transport electricity and electrical devices do not care which way it flows as long as current is flowing. Note: your TV and computer screen are actually flickering 60 times a second due to the alternating current that comes out of household plugs. Our eyesight does not work this fast, so we never notice it. However, if you film a TV or computer screen the effect is observable due to the mismatched frame rates of the camera and TV screen.) Electrical current coming out of your plug is an example.



- **Ammeter:** A device that measures electric current. You must break the circuit to measure the current. Ammeters have very low resistance; therefore you must wire them in series.

- **Voltmeter:** A device that measures voltage. In order to measure a voltage difference between two points, place the probes down on the wires for the two points. Do not break the circuit. Volt meters have very high resistance; therefore you must wire them in parallel.

- **Voltage source:** A power source that produces fixed voltage regardless of what is hooked up to it. A battery is a real-life voltage source. A battery can be thought of as a perfect voltage source with a small resistor (called internal resistance) in series. The electric energy density produced by the chemistry of the battery is called **emf**, but the amount of voltage available from the battery is called **terminal voltage**. The terminal voltage equals the emf minus the voltage drop across the internal resistance (current of the external circuit times the internal resistance.)

Key Equations:

- $I = \Delta q/\Delta t$; current is the rate at which charge passes by; the units of current are Amperes (1 A = 1 C/s).
- $\Delta V = I R$; the current flow through a resistor depends on the applied electric potential difference across it; the units of resistance are Ohms (1 Ω = 1 V/A).
- $P = I \cdot \Delta V$; the power dissipated by a resistor is the product of the current through the resistor and the applied electric potential difference across it; the units of power are Watts (1 W = 1 J/s).

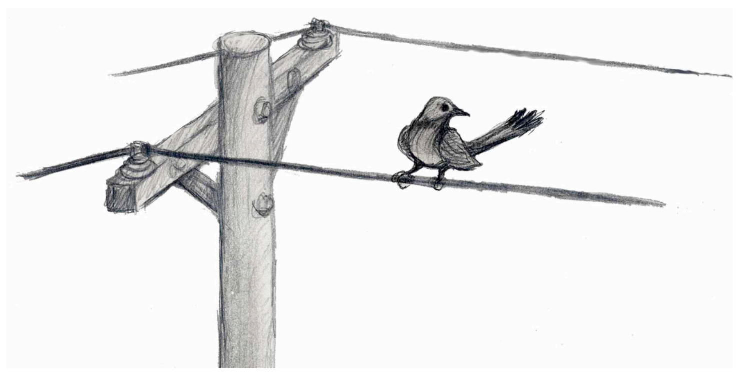
Electric Circuits Problem Set

1. The current in a wire is 4.5 A.
   a. How many coulombs per second are going through the wire?
   b. How many electrons per second are going through the wire?

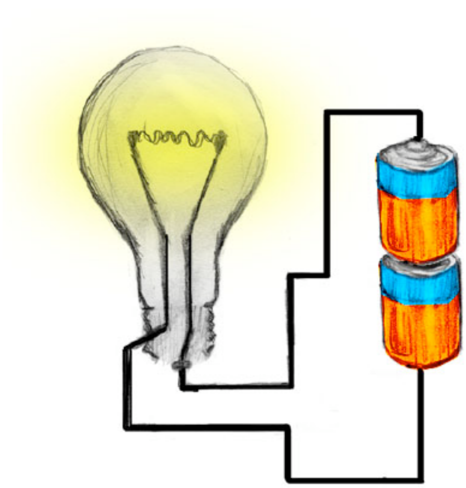
2. A light bulb with resistance of 80 Ω is connected to a 9 V battery.
   a. What is the electric current going through it?
   b. What is the power (i.e. wattage) dissipated in this light bulb with the 9 V battery?
   c. How many electrons leave the battery every hour?
   d. How many Joules of energy leave the battery every hour?

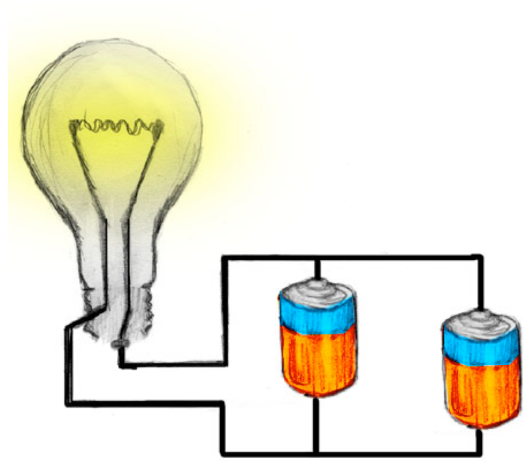
3. A 120 V, 75 W light bulb is shining in your room and you ask yourself…
   a. What is the resistance of the light bulb?
   b. How bright would it shine with a 9 V battery (i.e. what is its power output)?

4. A bird is standing on an electric transmission line carrying 3000A of current. A wire like this has about 3.0×10^{-5} Ω of resistance per meter. The bird's feet are 6 cm apart. The bird, itself, has a resistance of about 4×10^{5} Ω.
   a. What voltage does the bird feel?
   b. What current goes through the bird?
   c. What is the power dissipated by the bird?
   d. By how many Joules of energy does the bird heat up every hour?

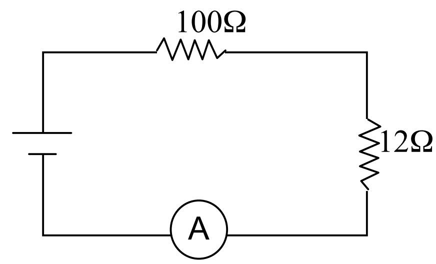


5. Which light bulb will shine brighter? Which light bulb will shine for a longer amount of time? Draw the schematic diagram for both situations. Note that the objects on the right are batteries, not resistors.



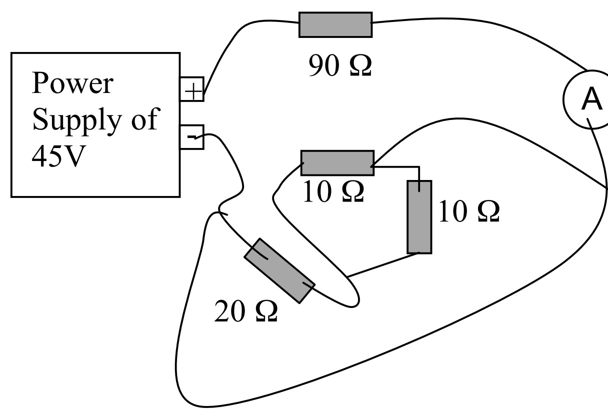


6. Regarding the circuit to the right.
   a. If the ammeter reads 2 A, what is the voltage?
   b. How many watts is the power supply supplying?
   c. How many watts are dissipated in each resistor?

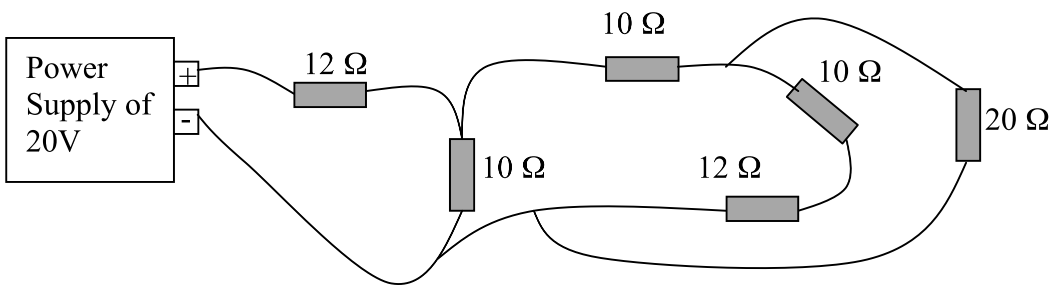


7. Three 82 Ω resistors and one 12 Ω resistor are wired in parallel with a 9 V battery.
   a. Draw the schematic diagram.
   b. What is the total resistance of the circuit?

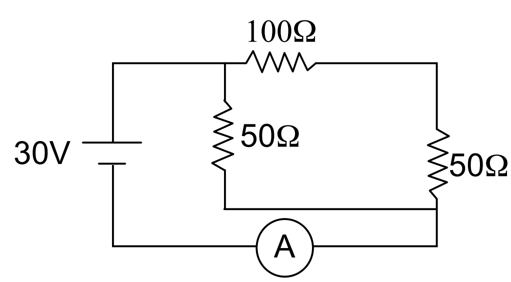
8. What will the ammeter read for the circuit shown to the right?



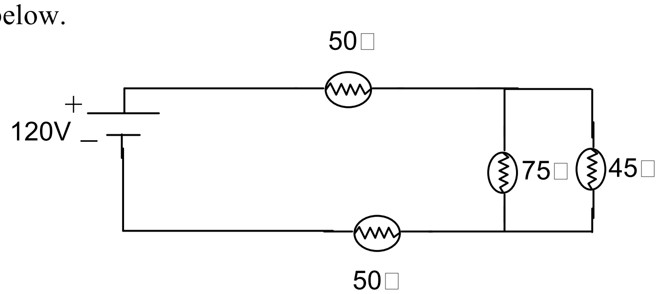
9. Draw the schematic of the following circuit.



10. What does the ammeter read and which resistor is dissipating the most power?

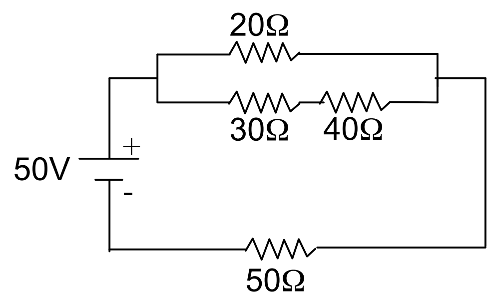


11. Analyze the ciruit below.



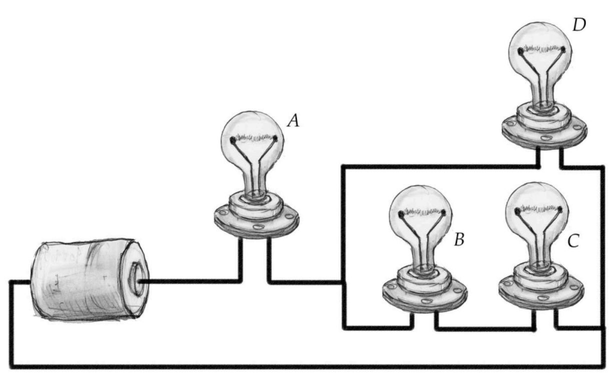
a. Find the current going out of the power supply
b. How many Joules per second of energy is the power supply giving out?
c. Find the current going through the 75 Ω light bulb.
d. Find the current going through the 50 Ω light bulbs (hint: it's the same, why?).
e. Order the light bulbs in terms of brightness
f. If they were all wired in parallel, order them in terms of brightness.

12. Find the total current output by the power supply and the power dissipated by the 20Ω resistor.



13. You have a 600 V power source, two 10Ω toasters that both run on 100 V and a 25 Ω resistor.
a. Show (with a schematic) how you would wire them up so the toasters run properly.
b. What is the power dissipated by the toasters?
c. Where would you put the fuses to make sure the toasters don't draw more than 15 Amps?
d. Where would you put a 25 Amp fuse to prevent a fire (if too much current flows through the wires they will heat up and possibly cause a fire)?

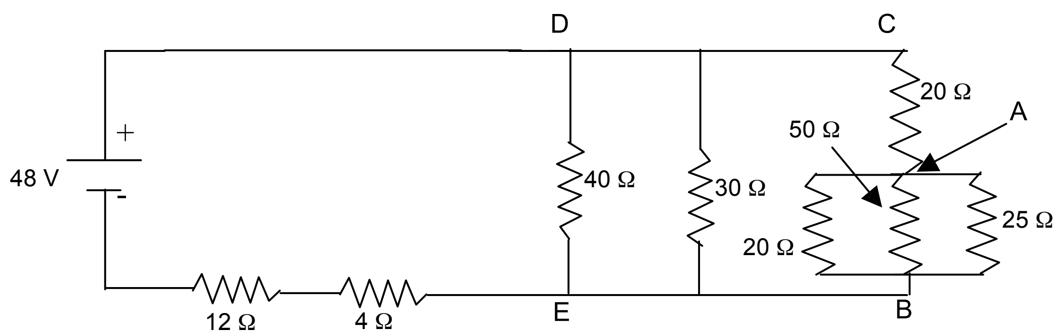
14. Look at the following scheme of four identical light bulbs connected as shown. Answer the questions below giving a justification for your answer:



a. Which of the four light bulbs is the brightest?
b. Which light bulbs are the dimmest?
c. Tell in the following cases which other light bulbs go out if:
i. bulb A goes out
ii. bulb B goes out
iii. bulb D goes out
d. Tell in the following cases which other light bulbs get dimmer, and which get brighter if:
i. bulb B goes out
ii. bulb D goes out

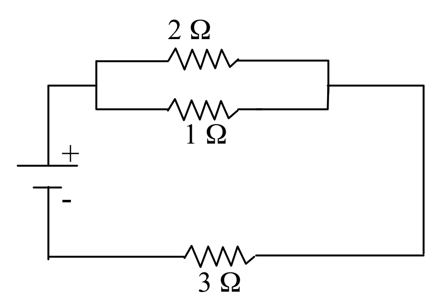
15. Refer to the circuit diagram below and answer the following questions.

a. What is the resistance between A and B?
b. What is the resistance between C and B?
c. What is the resistance between D and E?
d. What is the the total equivalent resistance of the circuit?
e. What is the current leaving the battery?
f. What is the voltage drop across the 12 Ω resistor?
g. What is the voltage drop between D and E?
h. What is the voltage drop between A and B?
i. What is the current through the 25 Ω resistor?
j. What is the total energy dissipated in the 25 Ω if it is in use for 11 hours?



16. In the circuit shown here, the battery produces an *emf* of 1.5 V and has an internal resistance of 0.5 Ω.

a. Find the total resistance of the external circuit.
b. Find the current drawn from the battery.
c. Determine the terminal voltage of the battery
d. Show the proper connection of an ammeter and a voltmeter that could measure voltage across and current through the 2 Ω resistor. What measurements would these instruments read?



17. Students measuring an unknown resistor take the following measurements:

Voltage (v)	Current (a)
15	.11
12	.08
10	.068
8	.052
6	.04
4	.025
2	.01

a. Show a circuit diagram with the connections to the power supply, ammeter and voltmeter.
b. Graph voltage vs. current; find the best-fit straight line.
c. Use this line to determine the resistance.
d. How confident can you be of the results?
e. Use the graph to determine the current if the voltage were 13 V.

18. Students are now measuring the terminal voltage of a battery hooked up to an external circuit. They change the external circuit four times and develop the following table of data:

Terminal Voltage (v)	Current (a)
14.63	.15
14.13	.35
13.62	.55
12.88	.85

a. Graph this data, with the voltage on the vertical axis.
b. Use the graph to determine the emf of the battery.
c. Use the graph to determine the internal resistance of the battery.
d. What voltage would the battery read if it were not hooked up to an external circuit?

19. Students are using a variable power supply to quickly increase the voltage across a resistor. They measure the current and the time the power supply is on. The following table of data is developed:

Time (sec)	Voltage (v)	Current (a)
0	0	0
2	10	1.0
4	20	2.0
6	30	3.0
8	40	3.6
10	50	3.8
12	60	3.5
14	70	3.1
16	80	2.7
18	90	2.0

a. Graph voltage vs. current
b. Explain the probable cause of the anomalous data after 8 seconds
c. Determine the likely value of the resistor and explain how you used the data to support this determination.
d. Graph power vs. time
e. Determine the total energy dissipation during the 18 seconds.

20. You are given the following three devices and a power supply of exactly 120v.
*Device X is rated at 60 V and 0.5 A
*Device Y is rated at 15 W and 0.5 A
*Device Z is rated at 120 V and 1800 w

Design a circuit that obeys the following rules: you may only use the power supply given, one sample of each device, and an extra, single resistor of any value (you choose). Also, each device must be run at their rated values.

21. Given three resistors, 200 Ω, 300 Ω and 600 Ω and a 120 V power source connect them in a way to heat a container of water as rapidly as possible.
a. Show the circuit diagram
b. How many joules of heat are developed after 5 minutes?

22. Construct a circuit using the following devices: a 120 V power source. Two 9 Ωresistors, device A rated at 1 A, 6 V; device B rated at 2 A, 60 V; device C rated at 225 w, 3 A; device D rated at 15w, 15 V.

23. You have a battery with an emf of 12 V and an internal resistance of 1.00 Ω. Some 2.00 A are drawn from the external circuit.
a. What is the terminal voltage
b. The external circuit consists of device X, .5 A and 6 V; device Y, 5 A and 10 V, and two resistors. Show how this circuit is connected.
c. Determine the value of the two resistors.

24. Students use a variable power supply an ammeter and three voltmeters to measure the voltage drops across three unknown resistors. The power supply is slowly cranked up and the following table of data is developed:

Current (ma)	Voltage R_1 (v)	Voltage R_2 (v)	Voltage R_3 (v)
100	2.1	3.6	5.1
150	3.0	5.0	7.7
200	3.9	7.1	10.0
250	5.0	8.9	12.7
300	6.2	10.8	15.0
350	7.1	12.7	18.0
400	7.9	14.3	20.0
450	9.0	16.0	22.0
500	10.2	18.0	25.0
600	12.5	21.0	31.0
700	14.0	25.0	36.0

a. Draw a circuit diagram, showing the ammeter and voltmeter connections.
b. Graph the above data with voltage on the vertical axis.
c. Use the slope of the best-fit straight line to determine the values of the three resistors.
d. Quantitatively discuss the confidence you have in the results
e. What experimental errors are most likely might have contributed to any inaccuracies.