Batteries and Circuit Elements
Challenge Problem Solutions

Problem 1:

(a) If charges flow very slowly through a metal, why does it not require several hours for light to come on when you throw a switch?

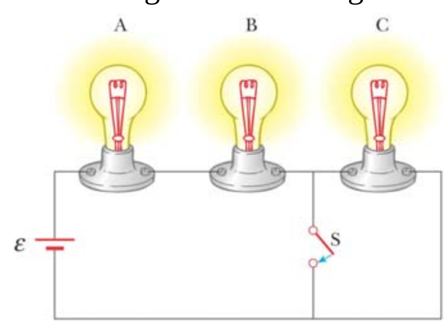
(b) What advantage does 120-V operation offer over 240 V? What are the disadvantages?

(c) Why is it possible for a bird to stand on a high-voltage wire without getting electrocuted?

(d) If your car's headlights are on when you start the ignition, why do they dim while the car is starting?

(e) Suppose a person falling from a building on the way down grabs a high-voltage wire. If the wire supports him as he hangs from it, will he be electrocuted? If the wire then breaks, should he continue to hold onto the end of the wire as he falls?

(f) A series circuit consists of three identical lamps connected to a battery as shown in the figure below. When the switch S is closed, what happens to the brightness of the light bulbs? Explain your answer.



Problem 1 Solution:

(a) Even though the average velocity of charges is very slow, when you connect a potential difference across a circuit (wire & light bulb), an electric field is established almost instantly (propagating near the speed of light) everywhere in the circuit, and the electrons begin to drift everywhere all at once.

(b) Both 120-V and 240-V lines can deliver injurious or lethal shocks, but there is a somewhat better safety factor with the lower voltage. On the other hand, a 240-V device requires less current to operate at the same power, and hence generates less heating and loss (I^2R) in wiring.

(c) The reason is because the potential on the entire wire is nearly uniform, and the potential difference between the bird's feet is approximately zero. Thus, the amount of current flowing through the bird is negligible, since the resistance through the bird's body between its feet is much greater than the resistance through the wire between the same two points.

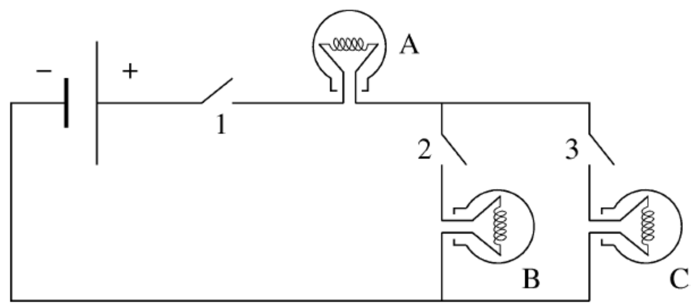
(d)The starter motor draws a significant amount of current from the battery while it is starting the car. This, coupled with the internal resistance of the battery, decreases the output voltage of the battery below its the nominal 12 V. This decrease in voltage decreases the current through (and brightness of) the headlights.

(e)As long as he only grabs one wire and does not touch anything that is grounded, he will be safe. If the wire breaks, *let go!* If he continues to hold on to the wire, there will be a large—and rather lethal—potential difference between the wire and his feet when he hits the ground.

(f)Closing the switch makes the switch and the wires connected to it a zero-resistance branch. All of the current through A and B will go through the switch and lamp C goes out, with zero voltage across it. With less total resistance, the current in the battery becomes larger than before and lamps A and B get brighter.

Problem 2:

The circuit below consists of a battery (with negligible internal resistance), three incandescent light bulbs (A, B & C) each with exactly the same resistance, and three switches (1, 2, & 3). In what follows, you may assume that, regardless of how much current flows through a given light bulb, its resistance remains unchanged. Assume that when current flows through a light bulb that it glows. The higher the current, the brighter the light will be.



In each situation (a, b, c) as described below, we want to know which light bulbs are glowing (and which are not) and how bright they are (relative to each other). *Always briefly discuss your reasoning.*

a. Switch #1 is closed; the others are open.
b. Switches #1 & #2 are closed; #3 is open
c. All three switches are closed
d. Now compare situations a, b & c. Which bulb is brightest of all, and which is faintest of all (bulbs which are off don't count).

Now replace bulb A by a wire of negligible resistance. We still have three switches and now two light bulbs (B & C).

e. Answer the questions b through d again for this situation.

Problem 2 Solutions:

(a)No bulbs glowing; no closed circuit anywhere and hence no current anywhere

(b)A & B glow with equal brightness as they are connected in series to the battery and thus the same current passes through each. C is still off.

(c)A, B & C all glow. A is brightest, for all current flows through it. B & C glow with equal but lesser brightness, as the current through A is split equally between B & C.

(d)Bulb A in case (c) is brightest of all; effective resistance of the bulb combination is decreased from that of part (b) by the addition of light bulb C in parallel with bulb B. By Ohm's law, more current is then drawn from the battery in case (c) as compared to case

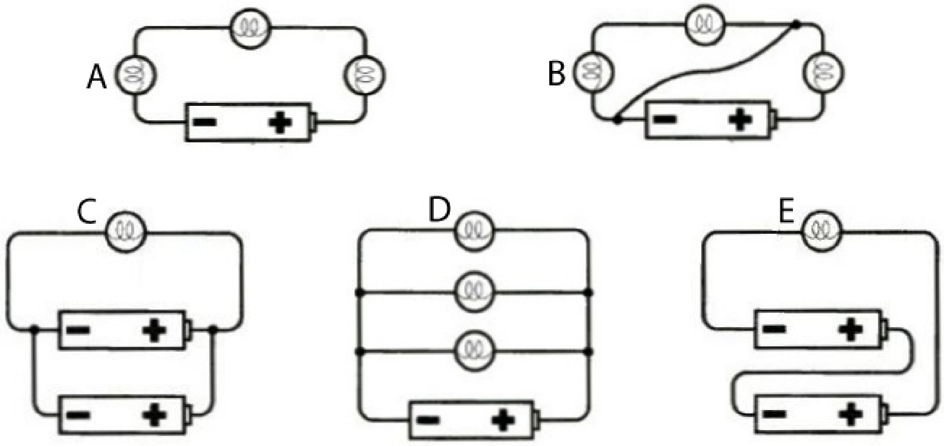
(b) leading to a brighter bulb A.

Bulbs B & C in case (c) are faintest of all. Let V be the battery voltage and R be the resistance of each bulb. The effective resistance of the circuit as a whole is 2R in case (b) and 1.5R in case (c). Thus the current through A is V/2R in case (b) and V/1..5R = 2V/3R in case (c). Therefore in case (b) the current through B is also V/2R, but in case (c) the current through B (and C) is half of 2V/3R or V/3R. This latter current is the smallest.

(e):
(e-b) B glowing, C off
(e-c) B & C glowing with equal brightness
(e-d) All on-bulb brightnesses are equal, for all bulbs have the full battery voltage across themselves, and therefore the same current goes through each.

Problem 3:

What is the correct order for the *total power* dissipated in the following circuits, from least to greatest? Assume all bulbs and all batteries are identical. Ignore any internal resistance of the batteries.



a) A < B = C < D < E

b) D < C < B = E < A

c) D < B < E < A < C

d) A = B < D < C < E

e) B < A < C = D < E

Problem 3 Solution:

a. The power dissipated in the circuits above is the equal to the power generated by the batteries. For a battery with a current I and an electromotive force V, the power generated by the battery is $P = IV$. The current from the battery in case A is $I_A = V/3R$, hence the power dissipated is $P_A = I_A V = V^2/3R$. The two resistors in series are shorted out in B, hence the current from the battery in case B is $I_B = V/R$, hence the power dissipated is $P_B = I_B V = V^2/R$. In case C, the current through the bulb is $I_C = V/R$. Because there is only one bulb, we can calculate the power dissipated across the bulb $P_C = I_C{}^2 R = V^2/R$. In case D the equivalent resistance is $R_D = R/3$. So the current from the battery in case D is $I_B = 3V/R$, hence the power dissipated is $P_D = I_D V = 3V^2/R$. Finally in case E, the electromotive force driving the current is $2V$, hence the current through the bulb is $I_E = 2V/R$. Because there is only one bulb, we can calculate the power dissipated across the bulb $P_E = I_E{}^2 R = 4V^2/R$. Therefore comparing our results we have that the correct order for the *total power* dissipated in the following circuits is $A < B = C < D < E$.