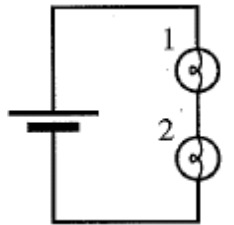# Solutions to Bulb questions

Note: We did some basic circuits with bulbs – in fact three main ones I can think of…I have summarized our results below. For the final exam, you must have an understanding of the brightness of bulbs in these three circuits (for like and unlike bulbs) as well as answers to questions 6 and 7. Questions 8 onwards are a little complicated and will not be on the final exam (simply because we did not discuss such circuits in class). I have the answers below for these questions for the sake of completeness.
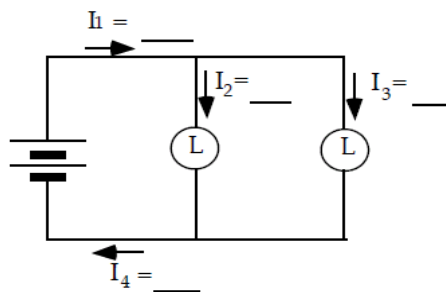
Basic Bulb circuits

Series circuit

If identical bulbs (same resistance, rated for the same watts) are in series, they will be the same brightness since the current through each bulb and the voltage across each bulb will be the same. So in the circuit below, if the bulbs are both round or both long, they will be equally bright.

If you have two different bulbs in series (e.g. a round bulb and a long bulb) the one with the greater resistance (the long bulb) will have the greater voltage across it. The same current flows through both the bulbs and since brightness depends on power output (voltage x current), the long bulb will be brighter.
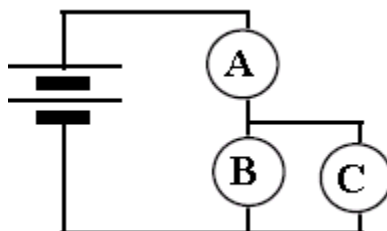
Parallel Circuit

If two identical bulbs (round or long) are in parallel, they will have the same brightness (same voltage across each and same current through each bulb).

If the two bulbs are not the same, then both bulbs will have the same voltage but greater current will flow through the bulb with the smaller resistance. So if a round bulb and a long bulb are in parallel, then the round bulb is brighter than the long bulb.

Combination of series and parallel

Clearly A must be brighter than B and C which are equally bright.

Using the current model we could say that A gets the entire battery current but B and C only get half the current.

Using the voltage model, we can say that because B and C combine to form a smaller resistance there is a smaller voltage drop across the parallel combination than bulb A. So using the voltage model, we end up with the same ranking: A > B=C.

But what happens if we unscrew C (or B)?

Then the current model tells us that B should get brighter since it gets all the battery current (just like A) and *the brightness of A should not change* since it is "upstream".

What did we actually observe in class?

When we unscrew C (or B), B gets *dimmer* and so does A!

The only way to understand this is to use the voltage model. When we unscrew C thus removing it from the circuit, the resistance of B is more than the parallel combination of B and C. The greater resistance reduces the current through the battery. Lesser current means less brightness for A. Since B is in series with A, it has the same brightness as A (lesser than when C was included in the circuit).

6) Light Bulbs

Does a light bulb obey Ohm's Law? Explain.

As you know by now, light bulbs do NOT obey Ohm's Law. How do we know this? Remember we measured the current through a bulb with different voltage values applied across it? The plot of voltage vs. current is NOT a straight line for a bulb. This may not have been obvious to you from your data unless you took a lot of data.

Why doesn't a bulb obey Ohm's Law? A bulb filament is designed to carry a large current. The bulb filament gets very hot and glows much like red-hot coal in a coal fire. When the filament gets hot its resistance (which is the inverse of the slope of the graph) increases. Thus the resistance of the bulb changes as it stays lit which means the slope of the graph does not stay constant.

7) *What determines the brightness of a light bulb? Is it the current through the bulb, the voltage across the bulb or both?*

Both. If you connect a long bulb and a round bulb in series, the long bulb glows but the round bulb does not. Both of them have the same current flowing through them (they are in series) but the long bulb has a greater voltage across it because it has more resistance (even though V=IR is not obeyed exactly, voltage drop does depend on the resistance). If you connect a round bulb and a long bulb in parallel, however, it is the round bulb that is brighter because now the voltage across both bulbs is the same but the current is larger through the round bulb (smaller resistance).

8) $\quad$ P = ΔV x I but assuming bulbs obey Ohm's law (well, approximately, at lower currents)

$I = \dfrac{\Delta V}{R}$. Combining these two relations, we have $P = \dfrac{(\Delta V)^2}{R}$.

At their normal operating temperatures (before the filament gets very hot), from $P = \dfrac{\Delta V^2}{R}$, the bulbs

display resistances $R = \dfrac{\Delta V^2}{P} = \dfrac{(120\ \text{V})^2}{60\ \text{W}} = 240\ \Omega$, and $\dfrac{(120\ \text{V})^2}{75\ \text{W}} = 190\ \Omega$, and $\dfrac{(120\ \text{V})^2}{200\ \text{W}} = 72\ \Omega$. The nominal 60 W lamp has greatest resistance. When they are connected in series, they all carry the same small current. Here the highest-resistance bulb glows most brightly (like the long bulb when connected in series with the round bulb) and the one with lowest resistance is faintest. This is just the reverse of their order of intensity if they were connected in parallel, as they are designed to be.

9) Note: Something like this will not be on the final exam since we did not do circuits with switches and shorting wires. However the voltage across the bulbs in series is still relevant for the final exam (and useful to know).

Suppose the battery voltage $\varepsilon = 12\ \text{V}$ and each lamp has $R = 2\ \Omega$. Before the switch is closed the current is $\dfrac{12\ \text{V}}{6\ \Omega} = 2\ \text{A}$. The potential difference across each lamp is $(2\ \text{A})(2\ \Omega) = 4\ \text{V}$. The power of each lamp is $(2\ \text{A})(4\ \text{V}) = 8\ \text{W}$, totaling 24 W for the circuit. 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 (b) lamp C goes out, with zero voltage across it. With less total resistance, the (c) current in the battery $\dfrac{12\ \text{V}}{4\ \Omega} = 3\ \text{A}$ becomes larger than before and (a) lamps A and B get brighter. (d) The voltage across each of A and B is $(3\ \text{A})(2\ \Omega) = 6\ \text{V}$, larger than before. Each converts power $(3\ \text{A})(6\ \text{V}) = 18\ \text{W}$, totaling 36 W, which is (e) an increase.

10) $\quad$ **Again – nothing like this will be on the final but this is good to know.**

Remember bulb brightness depends on current and voltage. The bulbs are identical (this is what we will assume since we were not told otherwise). Then bulbs that are in series should have the same current and the same voltage drop.

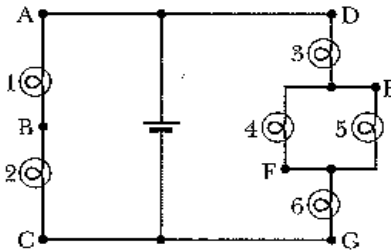So 1 = 2 since each of them have a voltage which is half the battery voltage and the same current.

3 = 6 and 4 = 5 (same reason as above)

However the parallel combination of 4 and 5 must be in series with 3 and 6. While 3 and 6 have the same voltage across them (same resistance), the parallel combination 4 and 5 will have less voltage across them (smaller resistance) and 4 and 5 will also have lesser current (since the current splits at the junction). Since the total voltage across DG is now split among more bulbs, 3 and 6 will have less voltage across them compared to 1 and 2 but more voltage across them than 4 and 5.
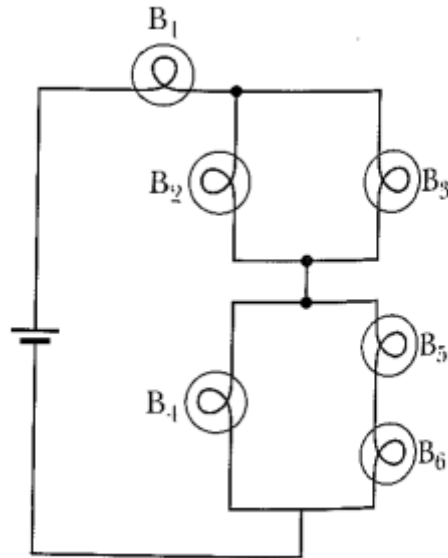
So the final ranking is:

1 = 2 > 3 = 6 > 4 = 5

11) $B_1 > B_4 > B_2 = B_3 > B_5 = B_6$

It actually helps to replace all the bulbs by resistors to analyze this circuit (keeping in mind that the measured currents and voltages will NOT be quite the same as that predicted by Ohm's Law).

This may be hard to understand with our limited exposure, but with identical bulbs, we can rank them based on voltage alone.

Clearly, B_1 is the brightest. Now B_2 and B_3 together offer a smaller resistance than B_4, B_5 and B_6. So the latter group has a greater voltage drop across the parallel branches. Still B_5 and B_6 get only half of this voltage across each which is less than the voltage drop across B_2 and B_3. B_4, of course gets all of it, so is brighter than B_2 and B_3.
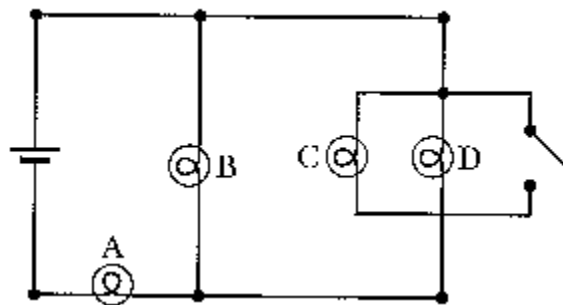
12) (Circuit on next page)

Assume the switch is open (as shown below – so there is a break in the wire). State which bulbs or combination of bulbs are in series and which ones are in parallel.

C, D and B are in parallel and the combination is in series with A.

b) Rank the bulbs according to brightness and explain your reasoning.

A gets all the battery current so should be brightest. B, C and D are in parallel and get the same current and the same voltage across them.

So the ranking is A>B=C=D.

c) Now assume the switch is closed. State which bulbs are in series and which ones are in parallel.

Closing the switch will make C and D go out (the current will take the easy path through the switch and bypass C and D. No current through the bulb means the bulb will not glow).

Then A and B are in series.

d) Rank the bulbs according to brightness and explain your reasoning.

A = B (series)

C and D do not light!