

General Physics - E&M (PHY 1308) Lecture Notes

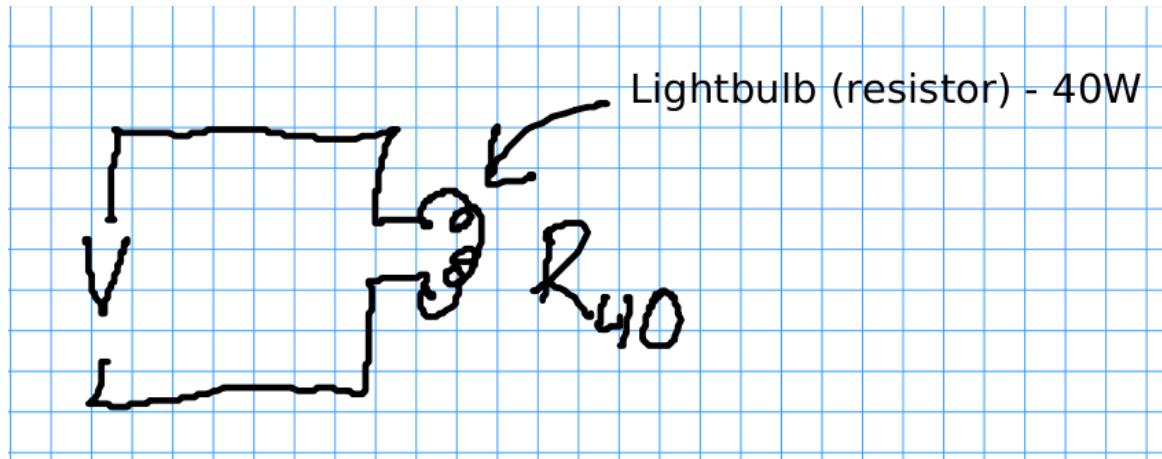
Lecture 016: Be a Physicist Day (Lightbulb Edition)

SteveSekula, 7 October 2010 (created 3 October 2010)

no tags

Series and Parallel Lightbulb Demo

Consider plugging a 40W lightbulb into a wall outlet ($V=110V$). We can compute the resistance of the bulb knowing its power output (40W) when plugged into the wall:



$$R_{40} = V^2 / P_{40} = 303\Omega$$

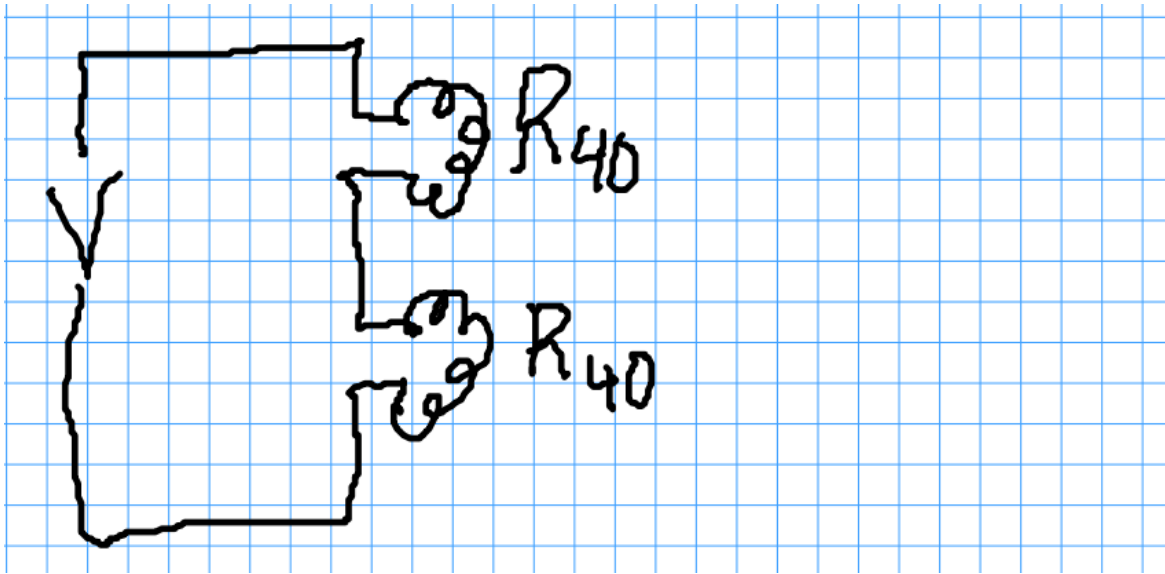
The current through such a circuit is $I_{40} = 0.36A$.

Consider doing the same thing with a 100W lightbulb. We can calculate its resistance in the same way:

$$R_{100} = V^2 / P_{100} = 121\Omega$$

A higher-wattage light bulb actually has a lower resistance! This makes sense, if you think about what shorting your house wiring will do - it will heat up the wiring so fast, due to the low resistance, that the wiring will glow, possibly melt, and definitely cause anything nearby to catch fire. A high-wattage lightbulb is closer to a short than a lower-wattage one. It outputs more light and heat, as a result.

Now, consider plugging in two of the 40W lightbulbs in series, so that current has to pass from the wall, through the first light, then through the second, and then back to the wall. The circuit is in its *steady-state* - the light output is constant and no charge is building up anywhere in the circuit. Thus, the current through both lightbulbs must be the same.



Let's then consider what happens to the power that can be maximally dissipated through each of the lightbulbs. Since the current is the same through both resistors, we can calculate it from Ohm's Law. The total resistance is the sum of the individual resistances:

$$R_{total} = 606\Omega$$

Thus:

$$I_{total} = I_1 = I_2 = V/R_{total} = 0.19A$$

which is half the current through the original 1-bulb circuit.

The voltage across each bulb is reduced from the total, but from conservation of energy the work per unit charge done across the whole circuit by the wall outlet is equal to the work per unit charge done in each resistor. Thus:

$$V = V_1 + V_2$$

$$V_1 = I_{total} R_1 = 55V$$

$$V_2 = I_{total} R_2 = 55V$$

which is half the voltage across a single lightbulb in the original 1-bulb circuit.

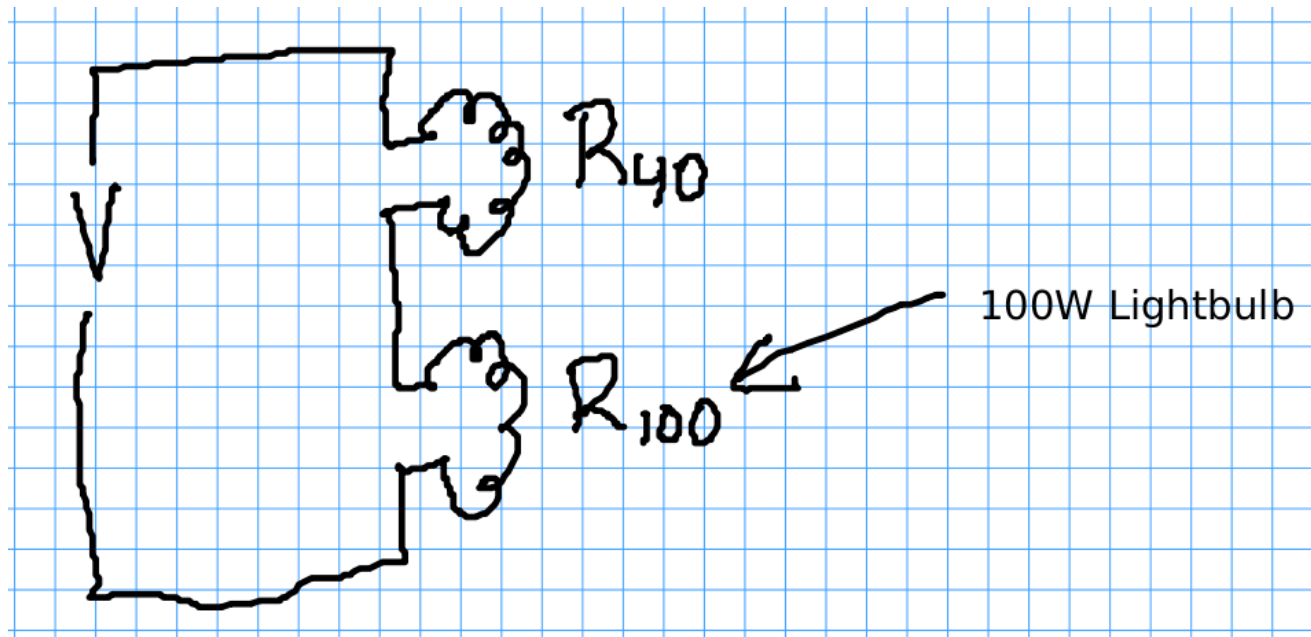
The maximum power that can be dissipated across either bulb is thus:

$$P_{max} = I_1 V_1 = I_2 V_2 = 10W$$

That's one-quarter the power that either lightbulb can output when hooked up to the wall by itself! This is because the voltage through each light is cut in half (due to their being in series), but also the current through the circuit is down by half (due to twice the resistance), so the power is down by a factor of 4.

So we expect each light to output about 1/4 of its value when it's alone in the circuit, and this is basically what we observe with the demo.

What about if we replace one of the 40W lightbulbs with a 100W lightbulb? Let's make a table of all the numbers in the circuit now.



V_{total}	110V
$R_{total} = R_{40} + R_{100}$	424Ω
$I_{total} = I_{40} = I_{100}$	0.26A
V_{40}	79V
V_{100}	31V
P_{40}	20.5W
P_{100}	8.1W

We see that the 40W bulb can maximally dissipate 20.5W in this setup - HALF of its value when plugged in alone. Thus we expect it to glow BRIGHTER when hooked up in series with a 100W (lower-resistance) bulb. The 100W bulb, however, can only maximally dissipate about 8W of power - less than 1/10th of its rated value. In fact, this is even too little power to really light the filament. In a dark room, you can barely see it glowing.

What happens if, instead, we hook up the 40W and 100W bulbs IN PARALLEL? Now the two bulbs are at the same potential, but do not have the same current flow (current will flow preferentially along the path of least resistance, so the 100W bulb should have MORE current than the 40W bulb).

The maximum power that can be dissipated through the 40W bulb is:

$$P = V^2/R = 110V/303\Omega = 40W$$

which is its rated power. What about the 100W bulb?

$$P = V^2/R = 110V/121\Omega = 100W$$

Again, its maximum rated power. In parallel, both lights are as bright as if they were plugged in alone to the wall.

So series bulbs = mood lighting. Parallel bulbs = study lighting.