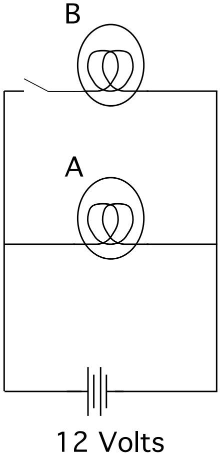
Resistors

The circuit on the right initially consists of a light bulb A powered by a single 12V battery. When a second, *identical* bulb B is added to the circuit by closing the switch, the brightness of bulb A

A. increases.

B. remains unchanged.

C. decreases.



ANS: B—The brightness of the bulb remains unchanged.

The potential difference across bulb A is 12V whether or not the switch is closed. Closing the switch allows additional current to pass through bulb B, but it does not change the current through bulb A.

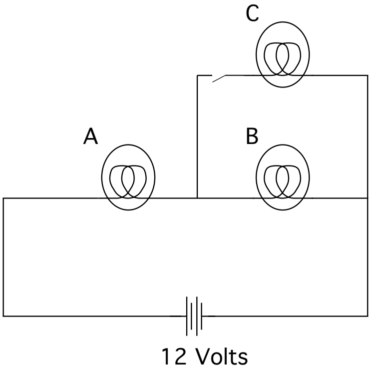
The brightness of bulb A is determined by the power it dissipates, which is equal to the product of the voltage across A and the current through it, or more appropriately in this case, $\Delta V^2/R$. This quantity does not change when the switch is closed.

The circuit on the right consists of two identical light bulbs A and B burning with equal brightness and a single 12V battery. When a third identical bulb C is added, the brightness of bulb A

A. increases.

B. remains unchanged.

C. decreases.



ANS: A—The brightness of bulb A increases.

When the switch is closed, bulbs B and C together present less resistance to current than bulb B alone. Adding a reduced B & C resistance to the unchanged resistance A thus provides an overall lower equivalent resistance for the whole circuit, so a greater current will flow at the battery's fixed voltage. All of this current from the battery must pass through bulb A, so it gets brighter.

This makes the potential difference across A greater than before the switch was closed, which also makes the potential difference across B less than before the switch was closed. Therefore, bulb B will get dimmer when the switch is closed.

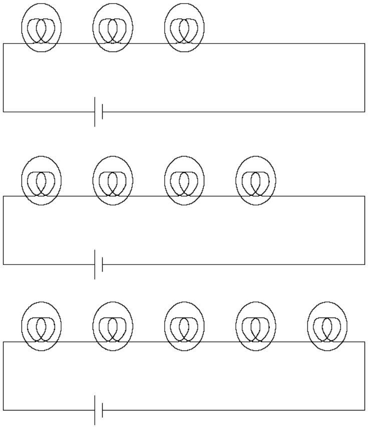
A group of light bulbs is connected as shown on the right, successively adding additional bulbs in series with a constant voltage supply. As each new bulb is added, the bulbs already in the circuit burn

A. brighter

B. the same

C. dimmer

compared to their original brightness.



ANS: C—The bulbs in the circuit get dimmer as we add bulbs in series.

The current is the same through all of the bulbs. Because the bulbs have equal resistances, they will have equal potential difference across them. These potential differences add to give a total potential difference ΔV_{tot} across the set.

As we add bulbs we don't change the potential difference across all bulbs remains the same, which means that the potential difference across each bulb must decrease. Therefore, the current through the bulbs must decrease and the bulbs must get dimmer.

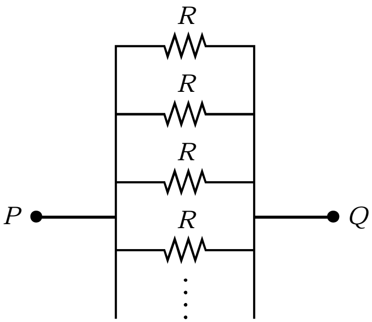
Adding resistors in series increases total resistance, which decreases current for a given potential difference across the set.

As more identical resistors R are added to the parallel circuit shown here, the total resistance between points P and Q

A. increases.

B. remains unchanged.

C. decreases.



ANS: C—The total resistance between P and Q decreases.

The potential difference ΔV is the same across each resistor. By Ohm's law the currents through all resistors are equal, $I = \Delta V/R$. The sum of the currents through all resistors is equal to the total current I_{tot} entering and exiting the parallel set.

An equivalent resistance would replace the set of resistors by a single resistor, R_{eq}, that has the same total current, I_{tot} when the same potential difference ΔV is applied. Therefore, R_{eq} is less than R and decreases as we add more resistors.

You can also think about it as I pointed out in notes. Every time you add a resistance in parallel, you are also adding a path. Without the additional resistor, that path has infinite resistance. When you put in the new resistor, you reduce the resistance along that path to a finite value, decreasing the equivalent resistance.

Warmup Question

A typical electric bill specifies how much electricity a household consumes in units of kilowatt-hours abbreviated kWh (i.e., 1000 watts of power times 1 hour of time). What is the corresponding proper SI unit for the quantity expressed as 1 kWh? Calculate the conversion factor between the two units. If the going rate is 10 cents/kWh, estimate the cost of raising a piano from street level to a tenth floor apartment, neglecting the cost of labor, pizza, and/or donuts. Please explain your reasoning fully and carefully.

ANS: One kilowatt of power is equal to $1000\,\text{W} = 1000\,\text{J/s}$.

One hour of time is equal to $3600\,\text{s}$.

So $1\,\text{kWh} = \left(10^3\,\text{J/s}\right)\left(3.6 \times 10^3\,\text{s}\right) = 3.6 \times 10^6\,\text{J}$.

To find the cost of raising a piano, let's estimate the mass of a piano to be around $150\,\text{kg}$ (about two people). This has a weight of around $mg = 1500\,\text{N}$. A building story is about $3\,\text{m}$ high, so we want to raise the piano about $30\,\text{m}$. This requires a total work of $(1500\,\text{N})\,(30\,\text{m}) = 4.5 \times 10^4\,\text{J}$. This equates to a little over $10^{-2}\,\text{kWh}$.
At a cost of $10\,\text{cents/kWh}$, the electricity would cost a little over $0.1\,\text{cents}$.

Warmup Question

Of the two categories, parallel and series, households in the US are wired almost exclusively in one way. Explain why that method is used and what would happen if the other method was used.

ANS: Household circuits are wired in **parallel**.

There are a couple reasons for this. Most importantly, we want to ensure that every appliance we plug into the wall is supplied with the same potential difference (voltage), no matter how many other appliances are operating at the same time. We can ensure this with parallel wiring.

Secondly, if appliances are wired in series, current must pass through *all* of them in order to pass through *any* of them. Think of an older string of Christmas lights where if one bulb burns out, all lights go out. This would not be a very good design for the use of electrical devices in the home. You would have to have all appliances in a series circuit running in order for any of them to run.

There is a big potential problem with parallel wiring, however. Every time you run a new device it adds to the total current delivered by the household wiring. If enough current is drawn, the wires can get hot and start a fire. The solution that household wiring uses is to have a number of distinct parallel circuits, each associated with a handful of outlets. If too many items on a circuit draw current at the same time, that circuit's "fuse" or "circuit breaker" will trip. This stops all current through that circuit. Putting an upper limit on the total current protects against electrical fires.