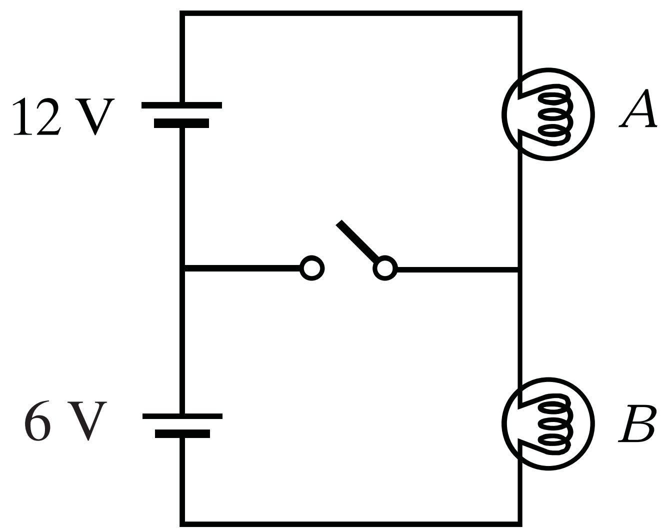
More on Kirchhoff’s Rules

The light bulbs in the circuit are identical. When the switch is closed,

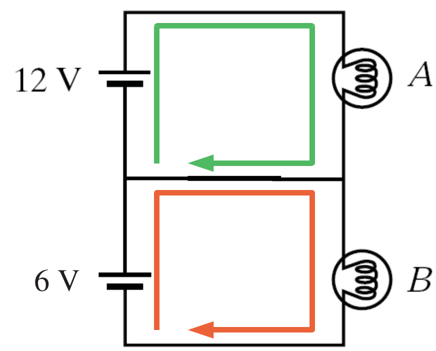


1. both go out.
2. the intensity of light bulb *A* increases.
3. the intensity of light bulb *A* decreases.
4. the intensity of light bulb *B* increases.
5. the intensity of light bulb *B* decreases.
6. some combination of 1–5 occurs.
7. nothing changes.

ANS: **6**—The intensity of bulb *A* increases, while the intensity of bulb *B* decreases.

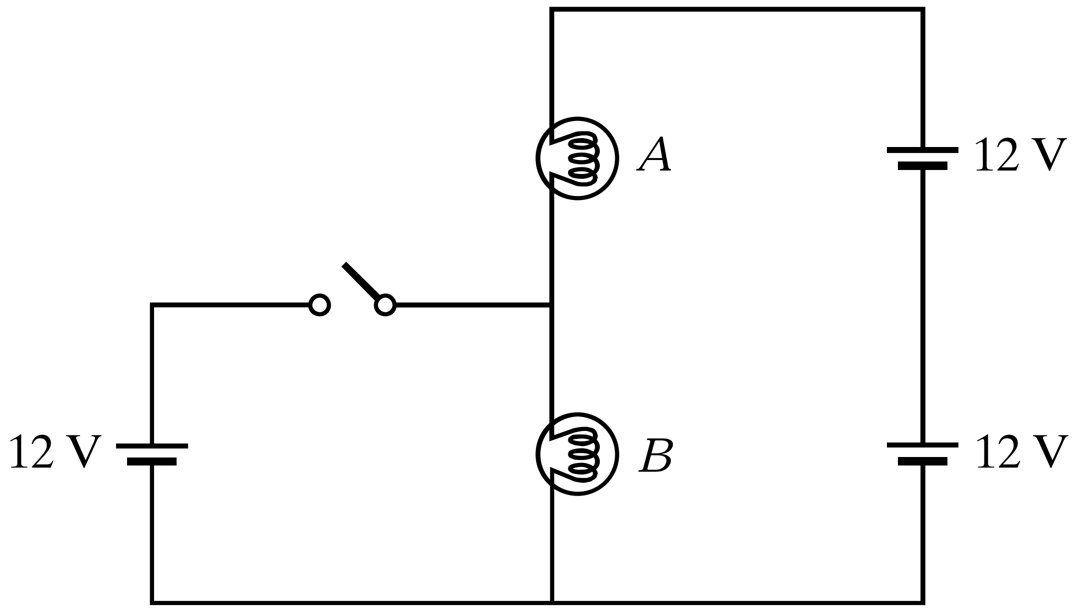
Following the analysis in the previous question, when the switch is open the two bulbs have a total potential difference of 18 V across them, so each bulb has a potential difference 9 V across it. The bulbs will be equally bright.

Now consider the case when the switch is closed, as shown in the diagram at the below. Analyzing the green loop, we see that the potential difference across bulb *A* rises to 12 V. Therefore, bulb *A* gets brighter. Analyzing the orange loop, we see that the potential difference across *B* is 6 V, so bulb *B* gets dimmer.



Because the bulbs have equal resistances, the current through bulb *A* will be twice as large as the current through bulb *B* when the switch is closed. Therefore, unlike the previous question, we see that there will be a current through the horizontal branch. The large current through *A* is split equally. Half will go down through bulb *B*, while the other half will move right-to-left through the closed switch.

The light bulbs in the circuit are identical. When the switch is closed,

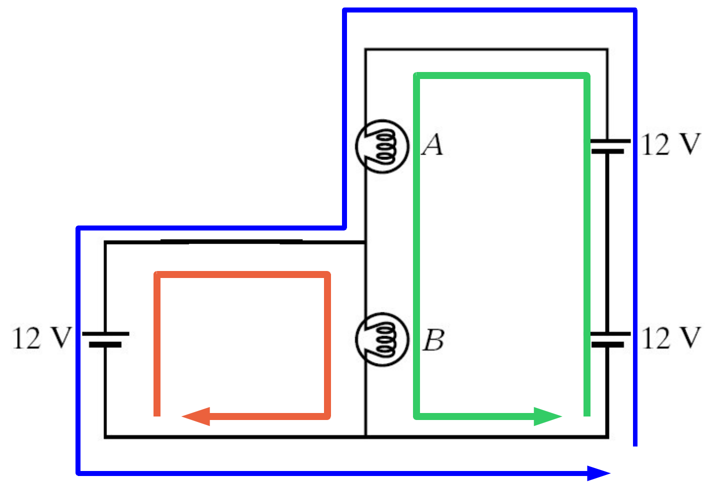


1. both go out.
2. the intensity of light bulb *A* increases.
3. the intensity of light bulb *A* decreases.
4. the intensity of light bulb *B* increases.
5. the intensity of light bulb *B* decreases.
6. some combination of 1–5 occurs.
7. nothing changes.

ANS: **7**—Nothing changes.

The analysis is similar to a prior problem. With the switch open, there is only one loop. The left-hand battery does not contribute any current. The currents through A and B are the same, so the potential differences across *A* and *B* will be equal:
$\Delta V_A = \Delta V_B = 12\,\mathrm{V}$.

Now let's investigate the system with the switch closed:

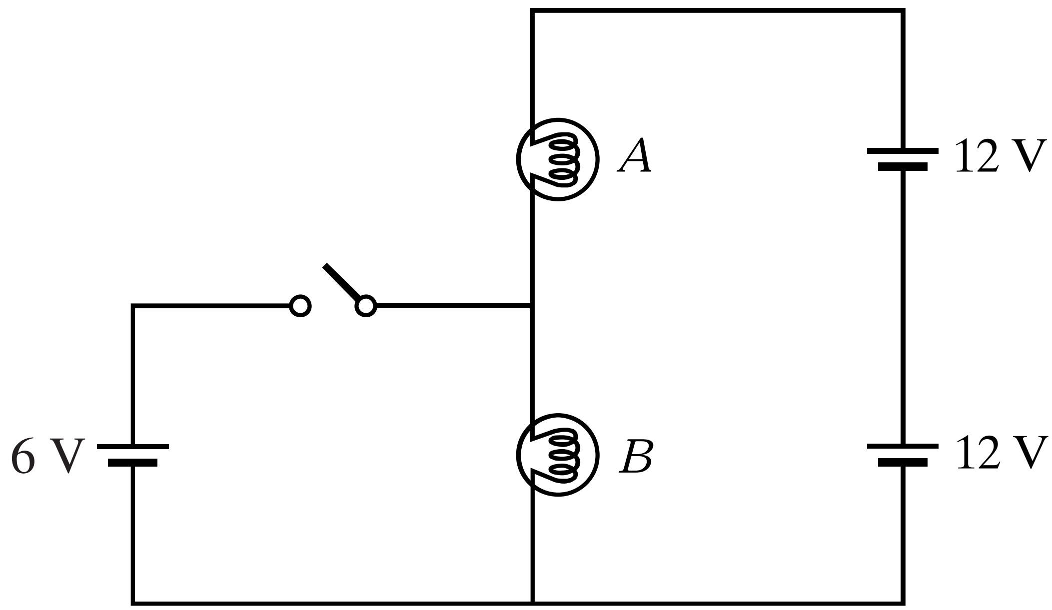


Following the red loop, we see that the potential difference goes up 12 V as we pass the battery, so it must drop by 12 V as we pass through bulb *B* and return to the starting point. Therefore, the potential difference across *B* remains 12 V, so the brightness of *B* will not change. Following the green loop, and using $\Delta V_B = 12\,\mathrm{V}$ leads us to the conclusion that ΔV_A must also still equal 12 V. Therefore, the brightness of the bulbs will not change.

Interestingly, we could also have learned that $\Delta V_A = 12\,\mathrm{V}$ by following the blue loop: the potential increases by 24 V along the right-hand side, drops by ΔV_A, then drops by 12 V as we pass through the left-hand battery before returning to the starting point.

Because bulbs *A* and *B* are identical and the potential differences across them are equal, the currents through them will be equal (the same). According to the junction rule for the point between *A* and *B*, equal amounts of current enter the junction from *A* and leave the junction for *B*. Therefore, even with the switch closed, the left-hand battery contributes no current to bulb *B*. (This may seem surprising to you. Go back over the analysis to convince yourself of this.)

The light bulbs in the circuit are identical. When the switch is closed,

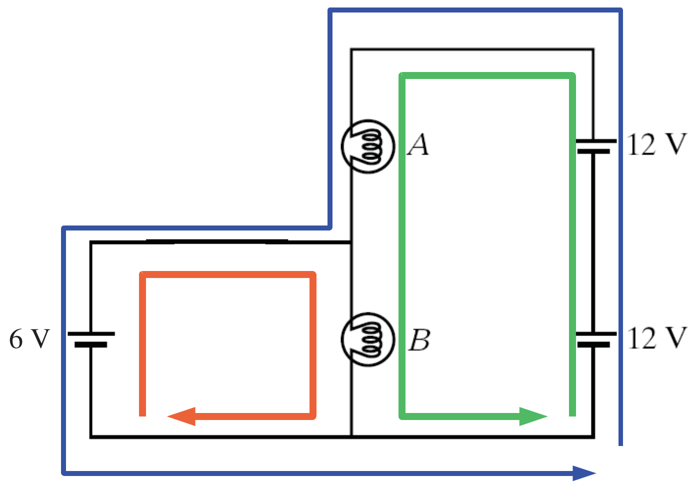


1. Bulb *A* is unaffected
2. The current through light bulb *B* increases
3. The current through light bulb *B* decreases
4. Bulb *B* has 2 currents going through it
5. The potential drops across the light bulbs are equal to each other
6. More than one of the above is true

ANS: **3**—The current through bulb *B* decreases.

Prior to the switch closing, the potential difference across the series combination of bulbs *A* and *B* is 24 V. The same current flows through these two identical bulbs, so they will have equal potential differences. Therefore, the potential difference across each bulb is 12 V.

The diagram below shows the situation after the switch is closed.



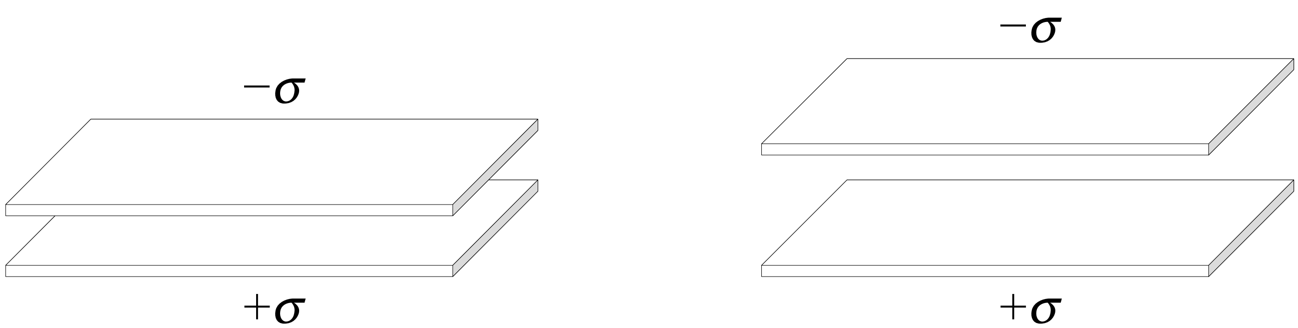
According to the blue path, the potential difference across bulb *A* is 18 V, so bulb *A* will get brighter after the switch is closed.

According to the red path, the potential difference across bulb *B* is now 6 V, meaning that bulb *B* will get dimmer after the switch is closed.

This finding is also verified by the green path. The potential difference across the series combination of bulbs *A* and *B* is still 24 V. After the switch is closed, $\Delta V_A + \Delta V_B = 18\,V + 6\,V = 12\,V$, as we should expect.

This also leads us to conclude that the current through *B* will be less than the current through *A*. Apparently, two-thirds of the current through *A* will branch off and pass through the 6 V battery!

Consider a pair of parallel-plate capacitors with identical plate areas and identical charge density on them. The distance between the plates is greater for one than for the other.



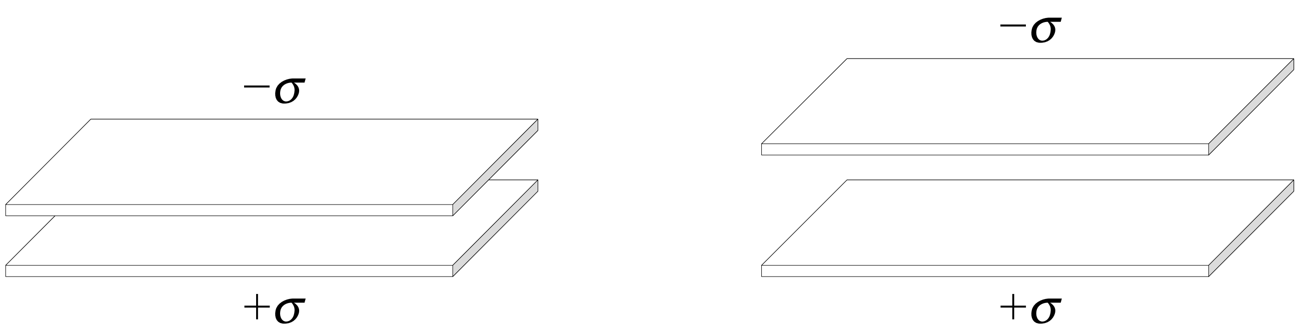
Which capacitor has the stronger electric field between the plates?

1. the one with closer plates
2. the one with more separated plates
3. the field is the same
4. more information needed

ANS: **3**—The field is the same in both cases.

As long as the plates are closer together than the plate size, the approximation we always use for parallel-plate capacitors, the field between the plates only depends on the charge density, or equivalently the ratio of charge to plate area. These quantities are the same for both capacitors.

Consider a pair of parallel-plate capacitors with identical plate areas and identical charge density on them. The distance between the plates is greater for one than for the other.



Which capacitor has the higher potential difference between its plates?

1. the one with closer plates
2. the one with more separated plates
3. the potential differences are the same
4. more information needed

ANS: **2**—The one with the more separated plates has the greater potential difference.

Because the field between the plates is uniform, the potential difference is just the product of the field and the plate separation, *d*. The field is the same for both capacitors, so the potential difference will be greater for the capacitor with the larger plate separation.

The parallel plates of a charged capacitor are connected to a power supply that establishes a constant potential difference between the plates. If we pull apart the plates of the capacitor (without changing the potential difference between the plates), does the energy stored in the capacitor

1. increase
2. decrease
3. stay the same
4. more information needed

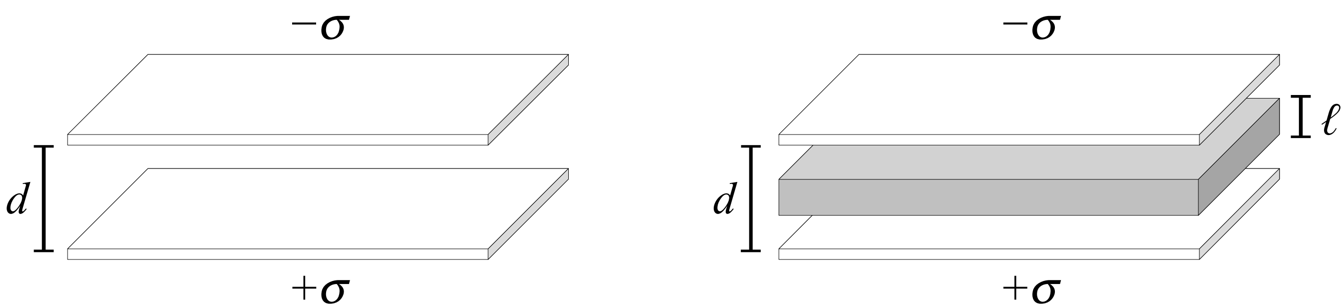
ANS: **2**—The energy stored in the plates decreases.

We know that the potential difference is fixed and the capacitance decreases as we separate the plates. Therefore, using the second energy expression above (involving C and V only) we see that the energy decreases. Apparently we do negative work on the capacitor (the capacitor does work on its surroundings) when we pull the plates apart. How can this be since the plates are still oppositely charged and attracted to each other? What is different from the previous example?

Because the capacitor is connected to a battery, charge is free to leave the capacitor and return to the battery. Separating the plates reduces the capacitance and therefore the charge stored on the capacitor maintained at the fixed voltage. Charges stored on each capacitor plate have the same sign and experience a repulsive force. The potential energy decreases as we reduce the capacitance and return some of the charge to the battery. This is not the case in the previous example, where all of the charges remain on the plates.

You can think of it this way: a battery supplies energy to a capacitor when it charges it. When you reduce the capacitance, some of the charge returns to the battery, taking energy with it.

Consider a capacitor made of two parallel metallic plates separated by a distance d. The top plate has a surface charge density $-\sigma$, the bottom plate $+\sigma$.



A slab of metal of thickness $\ell < d$ is inserted between the plates, not connected to either one. Upon insertion of the metal slab, the potential difference between the plates

1. increases
2. decreases
3. stays the same
4. more information needed

ANS: **2**—The potential difference between the plates decreases.

There is no electric field inside the metal slab because it is a conductor. There is a uniform electric field in the air gaps between the plates and the slab. The potential difference between the plates is just the product of the field and the distance over which there is a field, $\Delta V = E(d - \ell)$.