# Tutorial 10 Question

- After the switch S has been closed for a long time in the circuit shown, it is opened. (*a*) What is the charge on the capacitor just after the switch is opened? (*b*) Does the current flow clockwise or counter-clockwise? (*c*) How long does it take the capacitor to discharge to 0.1 V? (*d*) What is the voltage across the resistor at this time? (*e*) There is something missing in this circuit. What is it and why does it need to be there? (Hint: what happened when the switch was first closed?)
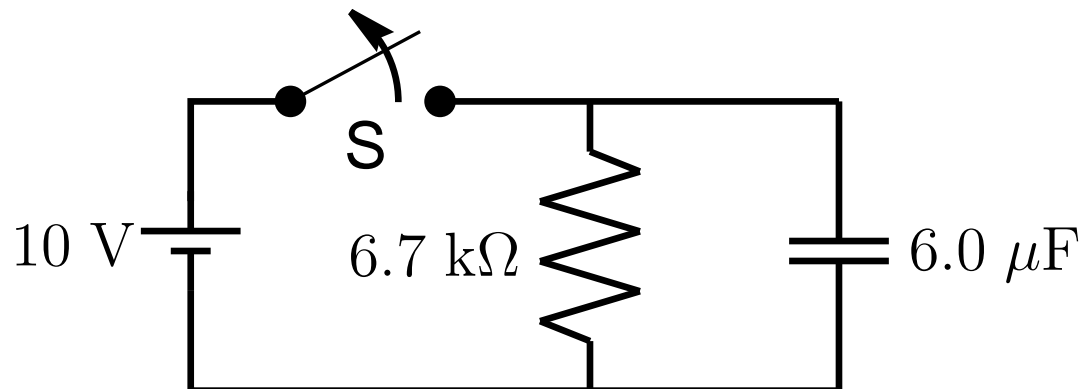
Solution

(*a*) What is the charge on the capacitor just after the switch is opened?

- If the switch has been closed a long time we can assume the voltage across the capacitor (or resistor) has reached 10 V. So the charge on the plates is

$$Q = CV = (6.0 \ \mu\text{F})(10 \ \text{V})$$
$$= 60 \ \mu\text{C}.$$

(*b*) Does the current flow clockwise or counter-clockwise?

- When the switch was closed a positive charge built up on the upper plate of the capacitor and a negative charge on the lower plate.

- When the switch is opened there is no longer a voltage holding those charges in place.

Solution, contd

(*b*) contd

- So the current flows from the upper plate to the lower along the wire—in a **counterclockwise** direction.
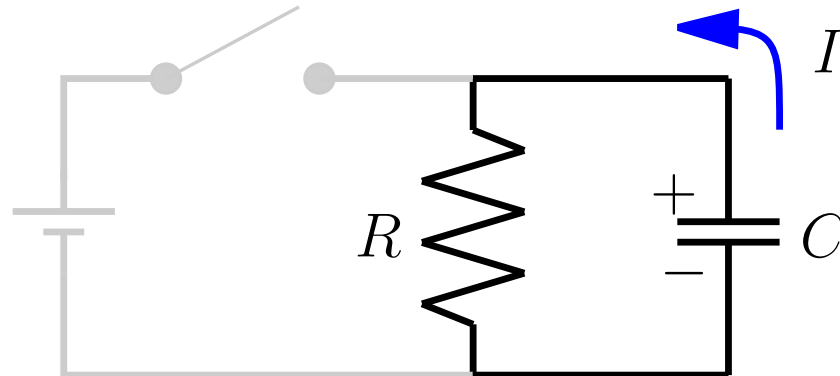
(*c*) How long does it take the capacitor to discharge to 0.1 V?

- We can now ignore the left loop in the circuit because the switch is open so we are just dealing with a capacitor and resistor in series.

Solution, contd

(*c*) contd

- In that case the time constant τ is just

$$\tau = RC = (6.7 \text{ k}\Omega)(6.0 \text{ }\mu\text{F}) = 40 \text{ ms.}$$

- In the steady state all the charge will leak off the capacitor so $V_\infty = \frac{Q_\infty}{C} = 0$. So the voltage across the capacitor follows

$$
\begin{aligned}
V(t) - V_\infty &= (V_0 - V_\infty) e^{-t/\tau} \\
V(t) - 0 &= (10 \text{ V} - 0)e^{-t/(40 \text{ ms})} \\
V(t) &= (10 \text{ V})e^{-t/(40 \text{ ms})}.
\end{aligned}
$$

Solution, contd

(*c*) contd

- We just need to solve $V(t) = 0.1$ V for t, which has the solution

$$
\begin{aligned}
t &= -\tau \ln \frac{V(t)}{V_0} \\
t &= -(40 \text{ ms}) \ln \frac{0.1 \text{ V}}{10 \text{ V}} \\
t &= 190 \text{ ms.}
\end{aligned}
$$

- The voltage across the capacitor reaches 0.1 V 190 ms after the switch is opened.

(*d*) What is the voltage across the resistor at this time?

- By Kirchhoff's loop rule, the voltage across the resistor must also be 0.1 V.

Solution, contd

(*e*) There is something missing in this circuit. What is it and why does it need to be there? (Hint: what happened when the switch was first closed?)

- When the switch was first closed it appears the voltage across the capacitor was immediately 10 V (from Kirchhoff's loop rule).

- But that doesn't make sense because it takes time for a charge (and hence, voltage) to build up on the capacitor.

- So the voltage drop around that part of the circuit must have been due to something else.

- The something else could have been the resistance of the wire (which we normally take to be negligible but can't in this case).

Solution, contd

(*e*) contd

- To represent the wire resistance we should insert a resistor r in the path of the capacitor:
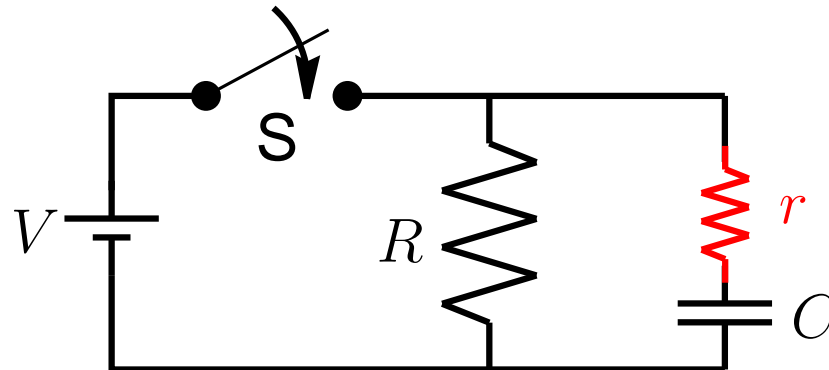
- As long as $r \ll R$ we can neglect it when talking about what happens after we open the switch.
- But r is important in determining how long the capacitor took to charge when the switch was first closed.