# Kirchhoff's Rules

- Sum of currents entering a junction must equal the sum of currents leaving the junction.
- The sum of potential differences across all the elements around any closed circuit loop must be zero.

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Figure 28.11

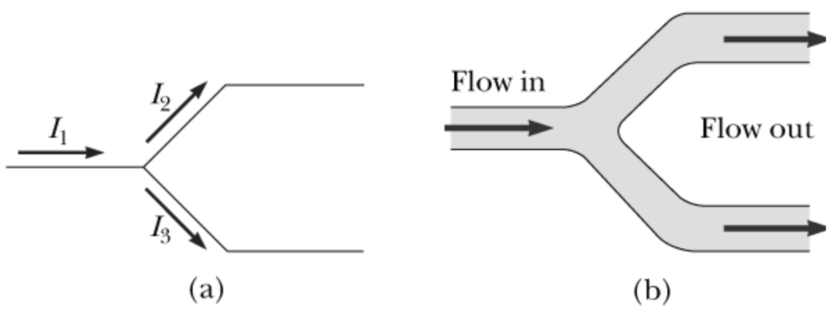


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Figure 28.12

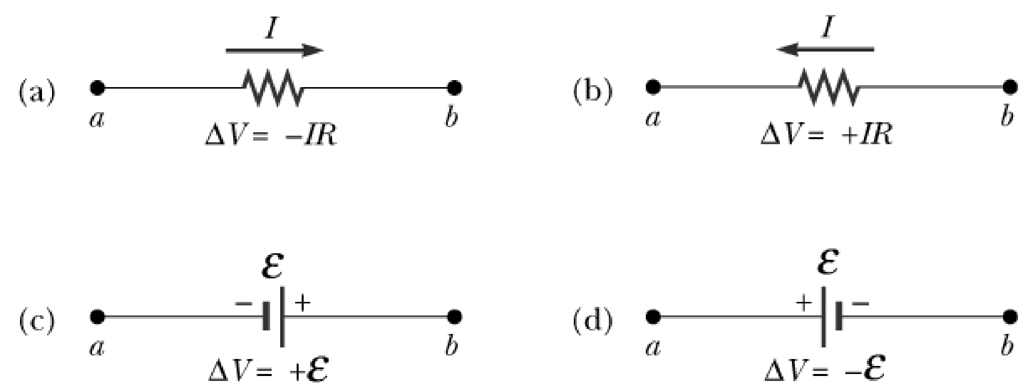


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Figure 28.13

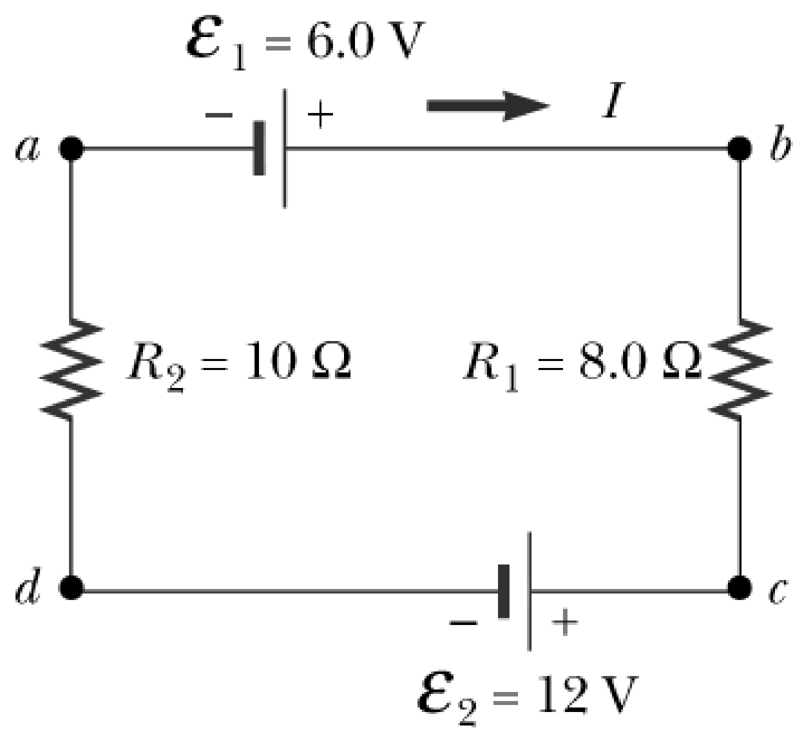


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Figure 28.15

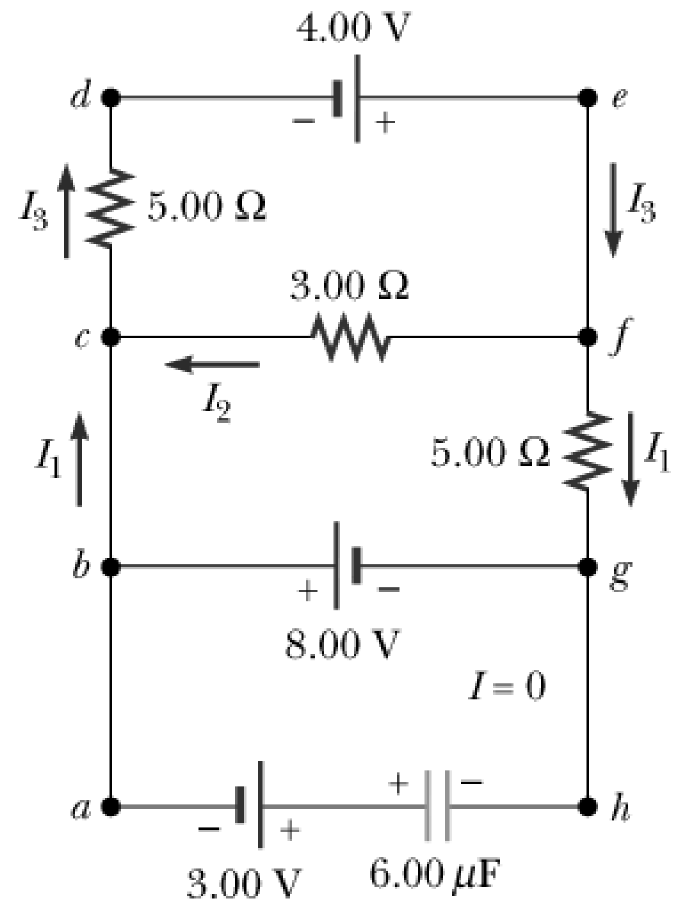


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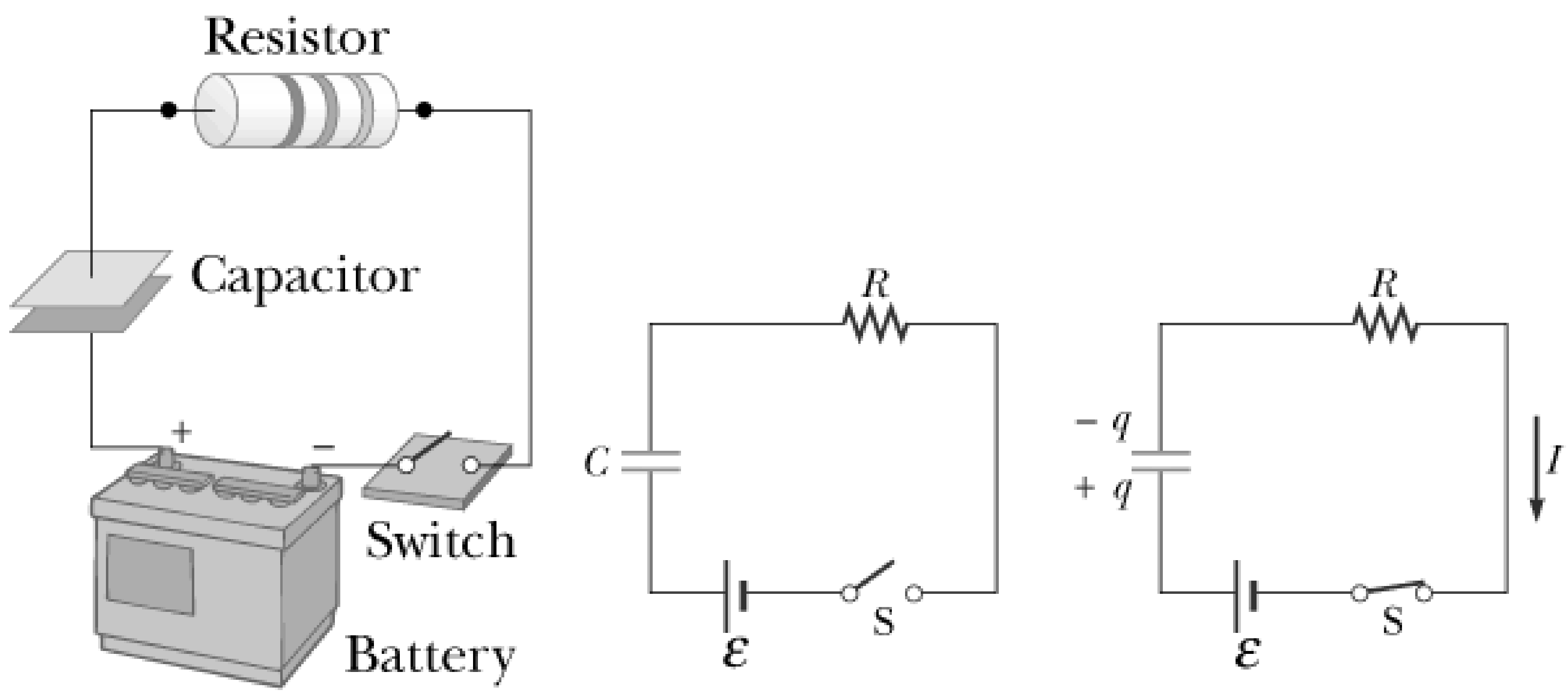
Figure 28.16




(a) (b) $t < 0$ (c) $t > 0$

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# RC Circuits

## Charging a Capacitor

- At any given time while the capacitor is charging:

$$\varepsilon - \frac{q}{c} - IR = 0$$

- At $t = 0$, $q = 0$:

$$I_0 = \frac{\varepsilon}{R}$$

- When the capacitor is fully charged $I = 0$, so the maximum charge $Q$:

$$Q = C\varepsilon$$

- Using $I = \frac{dq}{dt}$:

$$\frac{dq}{dt} = \frac{\varepsilon}{R} - \frac{q}{RC} \quad (1)$$
$$\frac{dq}{dt} = -\frac{q - C\varepsilon}{RC}$$
$$\frac{dq}{q - C\varepsilon} = -\frac{1}{RC}dt$$
$$\int_0^q \frac{dq}{q - C\varepsilon} = -\int_0^t \frac{1}{RC}dt$$
$$ln\left(\frac{q - C\varepsilon}{-C\varepsilon}\right) = -\frac{t}{RC}$$
$$q(t) = C\varepsilon(1 - e^{-t/RC}) = Q(1 - e^{-t/RC})$$

- Differentiating:

$$I(t) = \frac{\varepsilon}{R}e^{-t/RC} \quad (2)$$

- $RC$ is called the **time constant** $\tau$ of the circuit; represents the time it takes for the current to decrease to $1/e$ (1/2.71 =0.368) of the initial value.

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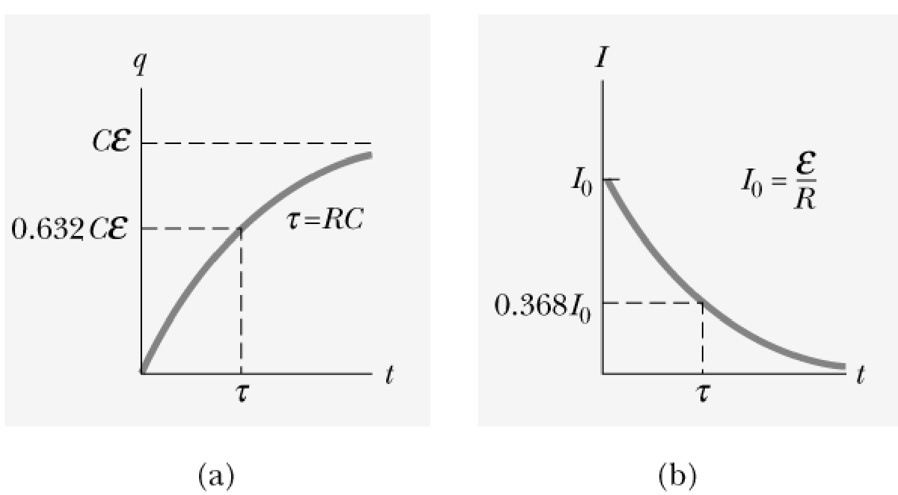
Figure 28.17

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- The total energy output of the battery is $Q\varepsilon = C\varepsilon^2$, but the energy stored in the capacitor is only half of this: $\frac{1}{2}Q\varepsilon = \frac{1}{2}C\varepsilon^2$. What happened to the rest of the energy ?

# RC Circuits

## Discharging a Capacitor

- At any given time while the capacitor is charging:

$$-\frac{q}{c} - IR = 0$$

- At $t = 0$, $q = Q$:
- Using $I = \frac{dq}{dt}$:

$$\frac{dq}{dt} = -\frac{q}{RC}$$
$$\frac{dq}{q} = -\frac{1}{RC}dt$$
$$\int_Q^q \frac{dq}{q} = -\int_0^t \frac{1}{RC}dt$$
$$ln\left(\frac{q}{Q}\right) = -\frac{t}{RC}$$
$$q(t) = Qe^{-t/RC}$$

- Differentiating:

$$I(t) = -\frac{Q}{RC}e^{-t/RC}$$

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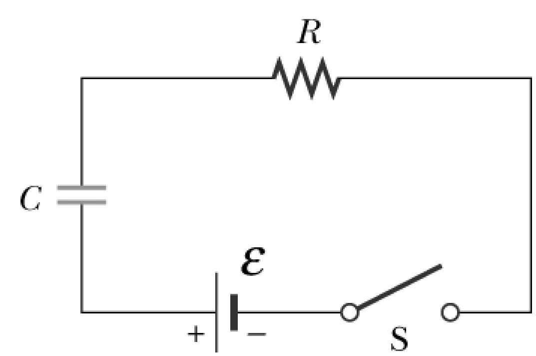
Figure 28.19

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