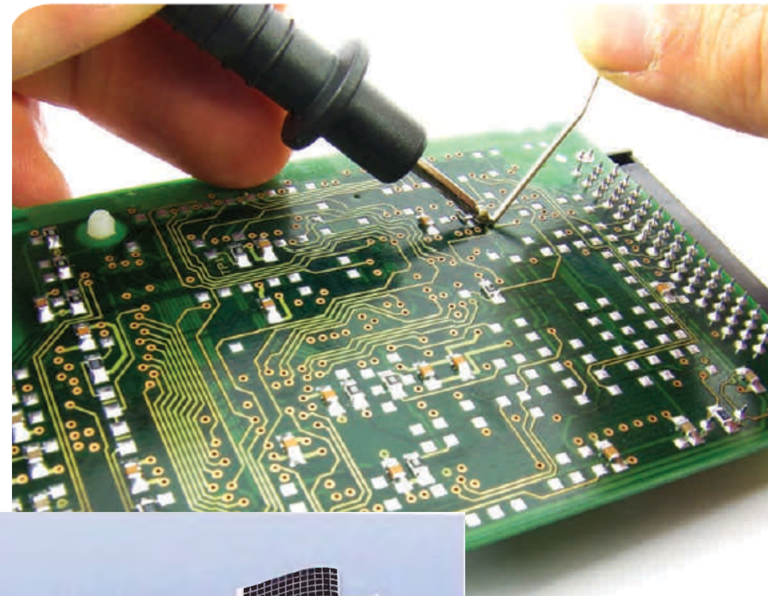
# PHY122 PHYSICS 2

## Chapter 7

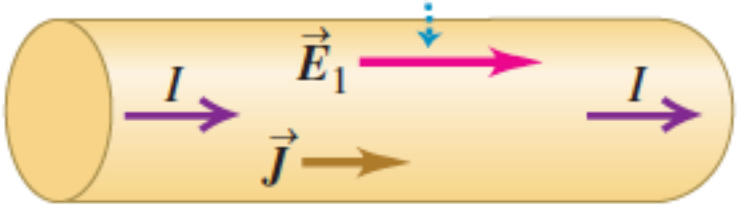
DC Current Circuits

7.1 Pumping Charges
7.2 Resistors in Series and Paralel
7.3 Kirchoff's Rules
7.4 RC Circuits



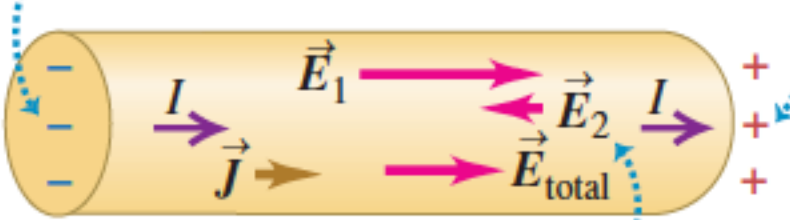
# 7.1 Pumping Charges

**(a)** An electric field $\vec{E}_1$ produced inside an isolated conductor causes a current.



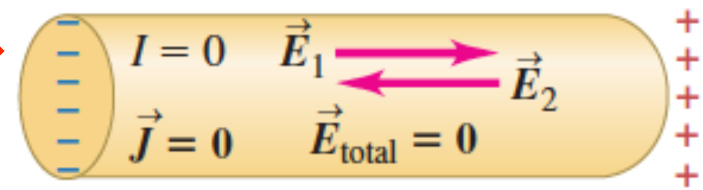

How is it possible to maintain a steady current in a complete circuit ?

**(b)** The current causes charge to build up at the ends.




The charge buildup produces an opposing field $\vec{E}_2$, thus reducing the current.

**(c)** After a very short time $\vec{E}_2$ has the same magnitude as $\vec{E}_1$; then the total field is $\vec{E}_{total} = 0$ and the current stops completely.



# 7.1 Pumping Charges

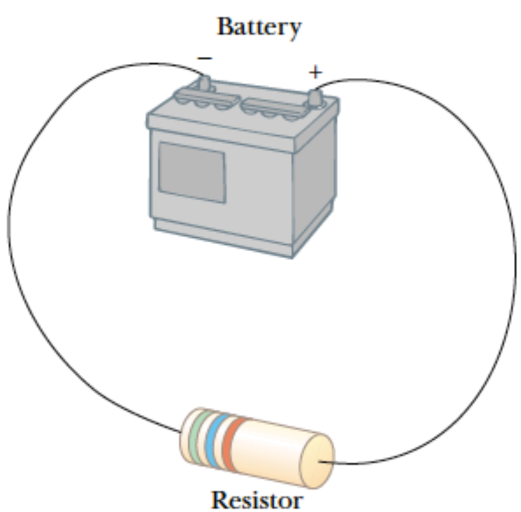
## A steady current in a complete circuit :

The water pours out of openings at the top, cascades down over the terraces and spouts (moving in the direction of decreasing gravitational potential energy), and collects in a basin in the bottom. A pump then lifts it back to the top (increasing the potential energy) for another trip

In an electric circuit there must be a device somewhere in the loop that acts like the water pump in a water fountain

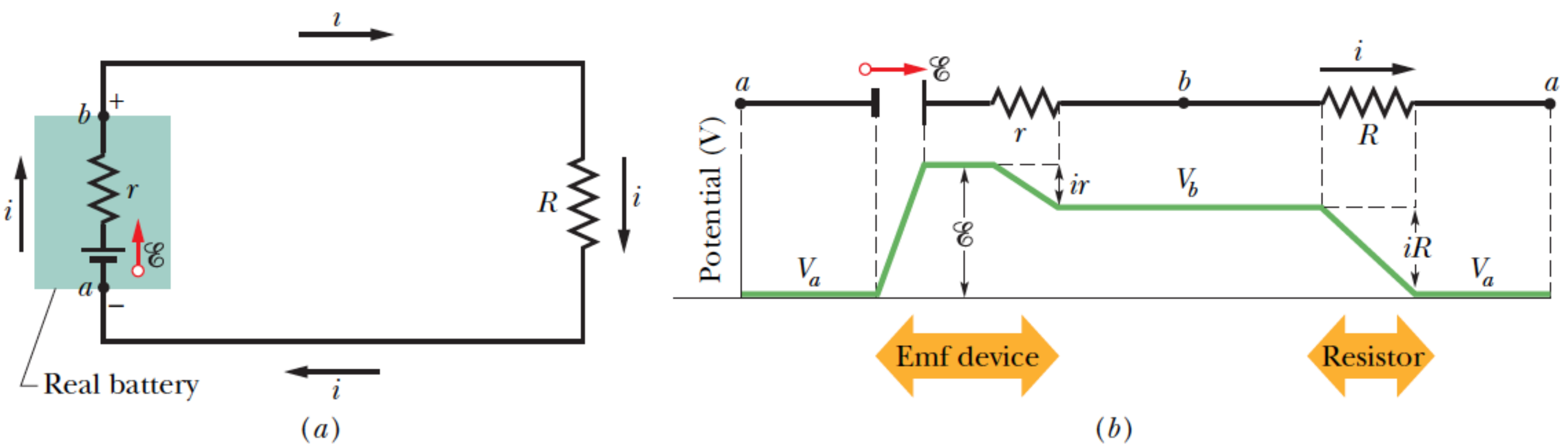
# 7.1 Pumping Charges

To produce a steady flow of charge, you need a "charge pump," a device that—by doing work on the charge carriers—maintains a potential difference between a pair of terminals. We call such a device an emf device, and the device is said to provide an emf , which means that it does work on charge carriers.




The term emf comes from the outdated phrase electromotive force, which was adopted before scientists clearly understood the function of an emf device.

# 7.1 Pumping Charges

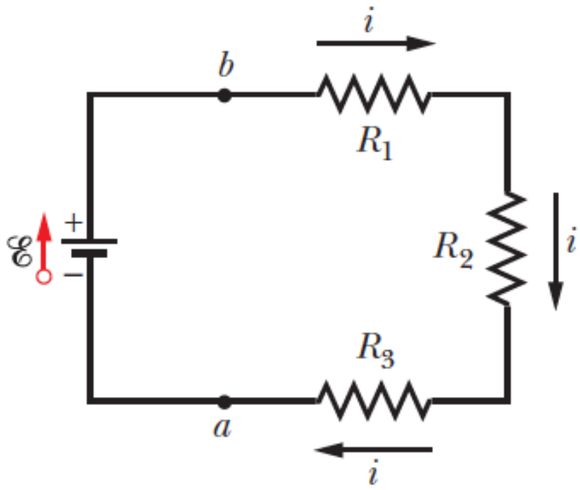


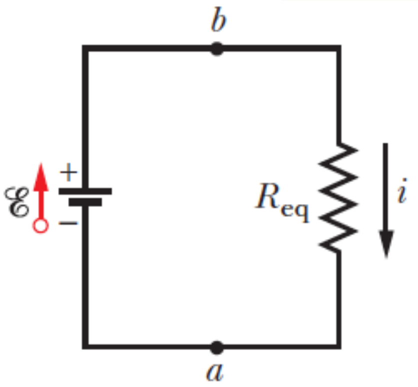

$$\varepsilon = ir + iR \Rightarrow i = \frac{\varepsilon}{R + r}$$

$$\Downarrow$$

$$i\varepsilon = P = i^2 r + i^2 R$$

# 7.2 Resistors in Series and Parallel



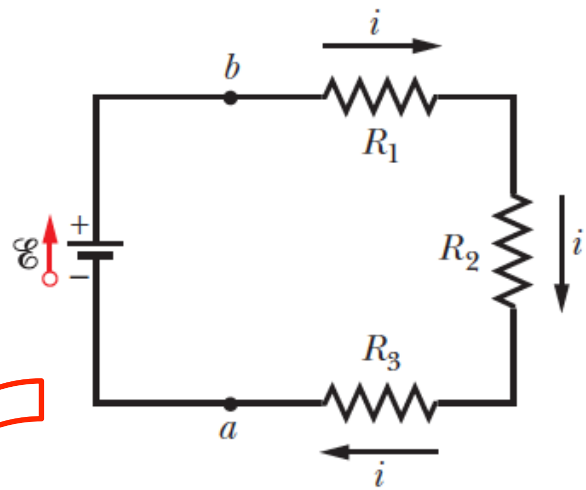



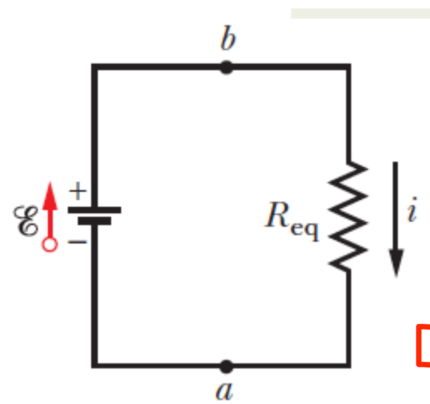

✔**When a potential difference V is applied across resistances connected in series, the resistances have identical currents i.**

✔**The sum of the potential differences across the resistances is equal to the applied potential difference V.**

Resistances connected in series can be replaced with an equivalent resistance $R_{eq}$ that has the same current i and the same total potential difference V as the actual resistances.

# 7.2 Resistors in Series and Parallel




$$\varepsilon = iR_1 + iR_2 + iR_3$$

$$i = \frac{\varepsilon}{R_1 + R_2 + R_3}$$

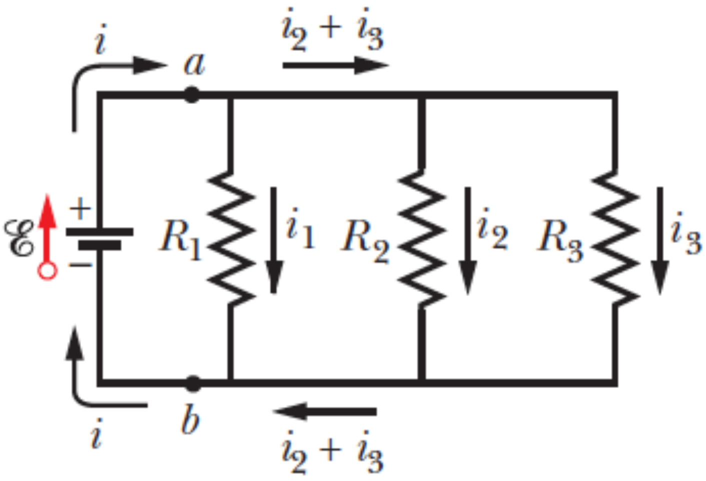
$$\varepsilon = iR_{eq}$$

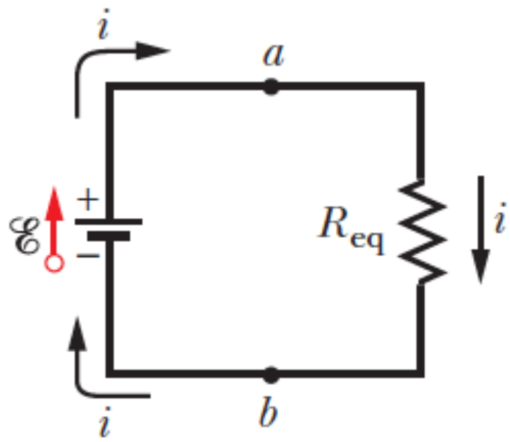
$$i = \frac{\varepsilon}{R_{eq}}$$

$$R_{eq} = R_1 + R_2 + R_3$$

$$R_{eq} = \sum_{j=1}^{n} R_j$$

# 7.2 Resistors in Series and Parallel

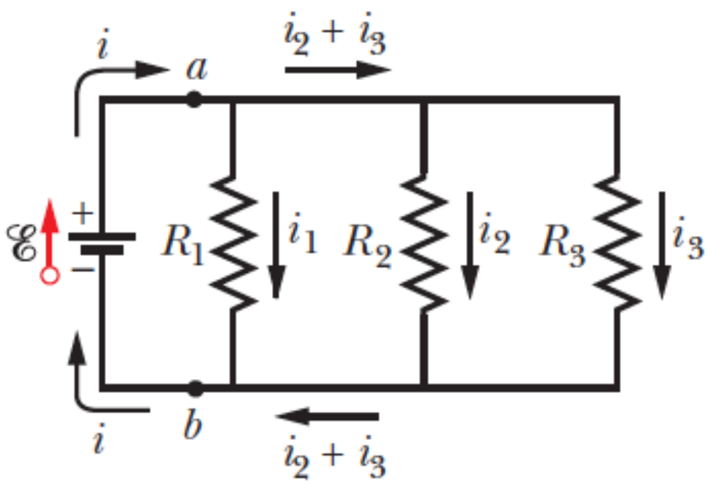


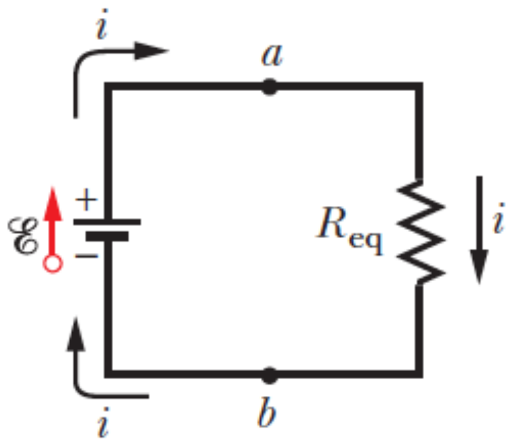




**✔When a potential difference V is applied across resistances connected in parallel, the resistances all have that same potential difference V.**

Resistances connected in parallel can be replaced with an equivalent resistance $R_{eq}$ that has the same potential difference V and the same total current i as the actual resistances.

# 7.2 Resistors in Series and Paralel




$$i = i_1 + i_2 + i_3$$

$$i = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3}$$

$$i = \frac{V}{R_{eq}}$$

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

$$\frac{1}{R_{eq}} = \sum_{j=1}^{n} \frac{1}{R_j}$$

# 7.2 Resistors in Series and Paralel

**Table 27-1**

**Series and Parallel Resistors and Capacitors**

| Series | Parallel | Series | Parallel |
|---|---|---|---|
| Resistors | | Capacitors | |
| $R_{eq} = \sum_{j=1}^{n} R_j$ Eq. 27-7 | $\frac{1}{R_{eq}} = \sum_{j=1}^{n} \frac{1}{R_j}$ Eq. 27-24 | $\frac{1}{C_{eq}} = \sum_{j=1}^{n} \frac{1}{C_j}$ Eq. 25-20 | $C_{eq} = \sum_{j=1}^{n} C_j$ Eq. 25-19 |
| Same current through all resistors | Same potential difference across all resistors | Same charge on all capacitors | Same potential difference across all capacitors |

# 7.3 Kirchoff's Rules

**Junction rule :** **The sum of the currents entering any junction in a circuit must equal the sum of the currents leaving that junction:**

$$\sum_{junction} i = 0$$

**Loop rule:** **The sum of the potential differences across all elements around any closed circuit loop must be zero:**

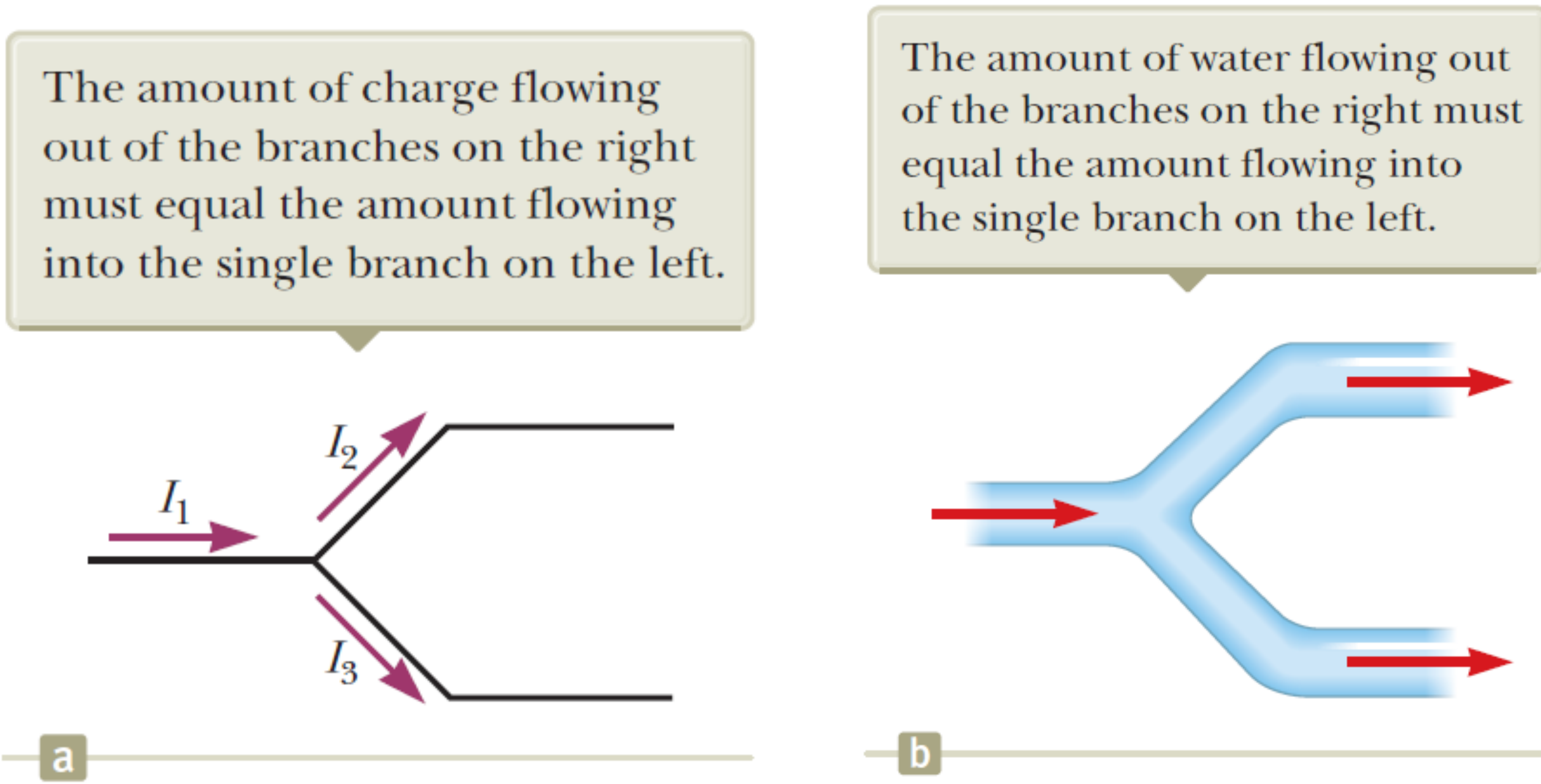
$$\sum_{\substack{closed\\loop}} \Delta V = 0$$

# 7.3 Kirchoff's Rules

**Junction rule :** **The sum of the currents entering any junction in a circuit must equal the sum of the currents leaving that junction:**

$$\sum_{kavşak} i = 0$$

it is a statement of conservation of electric charge



# 7.3 Kirchoff's Rules

**Loop rule: The sum of the potential differences across all elements around any closed circuit loop must be zero:**

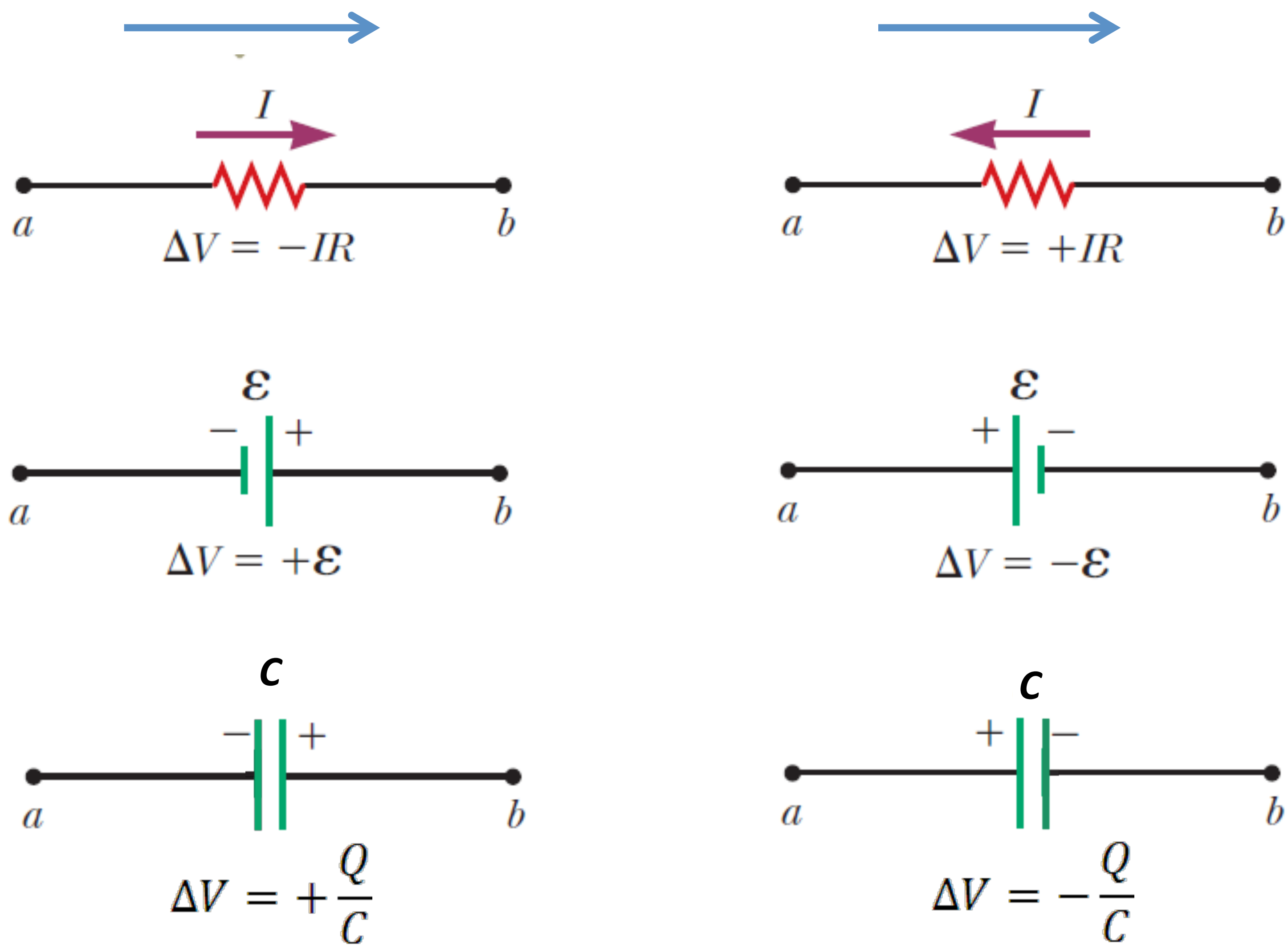
$$\sum_{\substack{closed \\ loop}} \Delta V = 0$$

It follows from the law of conservation of energy

When applying Kirchhoff's second rule in practice, we imagine traveling around the loop and consider changes in electric potential, rather than the changes in potential energy described in the preceding paragraph.

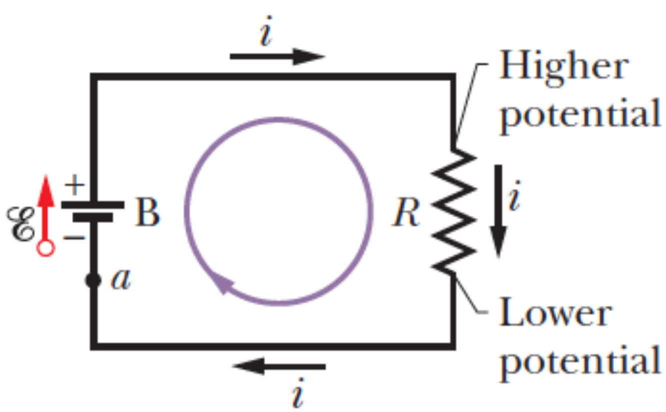
**You should note the following sign conventions when using the second rule**

# 7.3 Kirchoff's Rules



# 7.3 Kirchoff's Rules

The battery drives current through the resistor, from high potential to low potential.

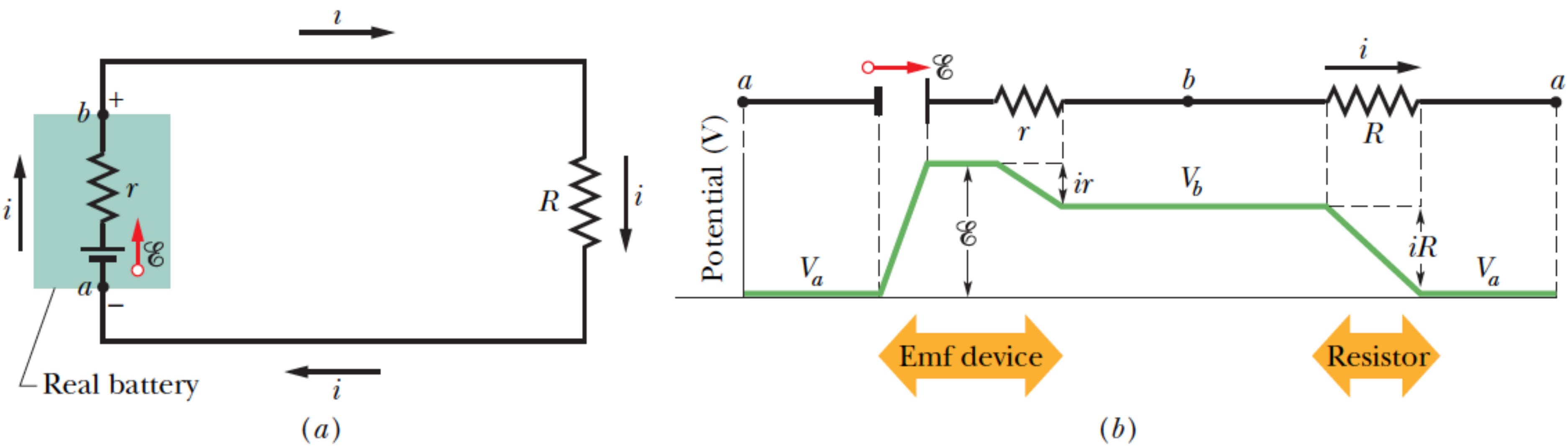



$$V_a + \varepsilon - iR = V_a$$

$$\varepsilon - iR = 0$$

$$\varepsilon = iR$$

# 7.3 Kirchoff's Rules

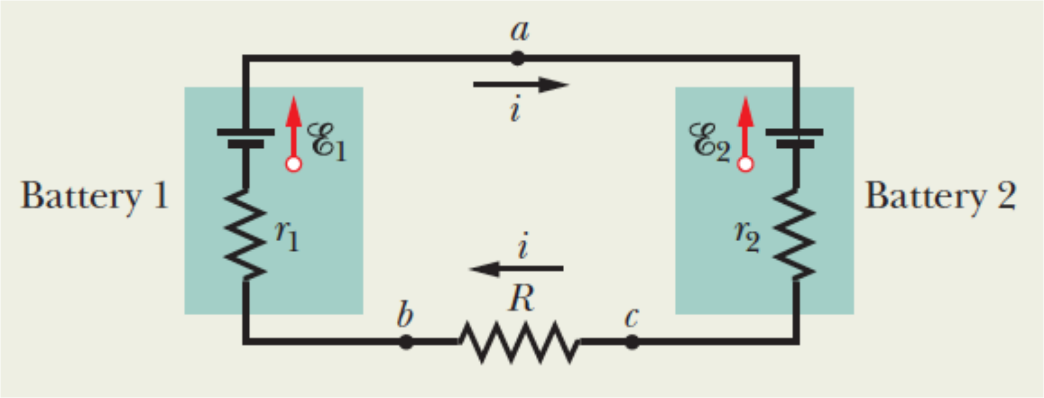



$$\varepsilon - ir - iR = 0 \Rightarrow i = \frac{\varepsilon}{r + R}$$

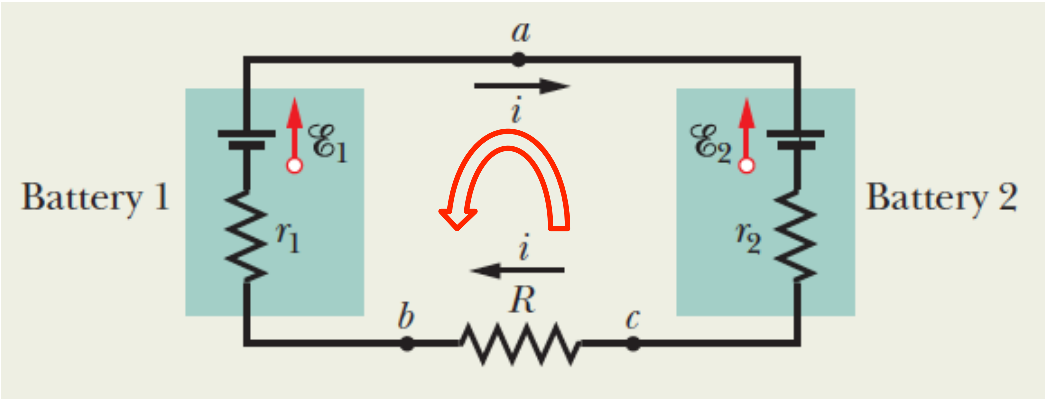
**Example:** The emfs and resistances in the circuit of Fig. blow have the following values:

$$\varepsilon_1 = 4.4V,\ \varepsilon_2 = 2.1V,$$
$$r_1 = 2.3\Omega,\ r_2 = 1.8\Omega,\ R = 5.5\Omega$$

a) What is the current i in the circuit?
b) What is the potential difference between the terminals of battery 1 in Fig. below ?



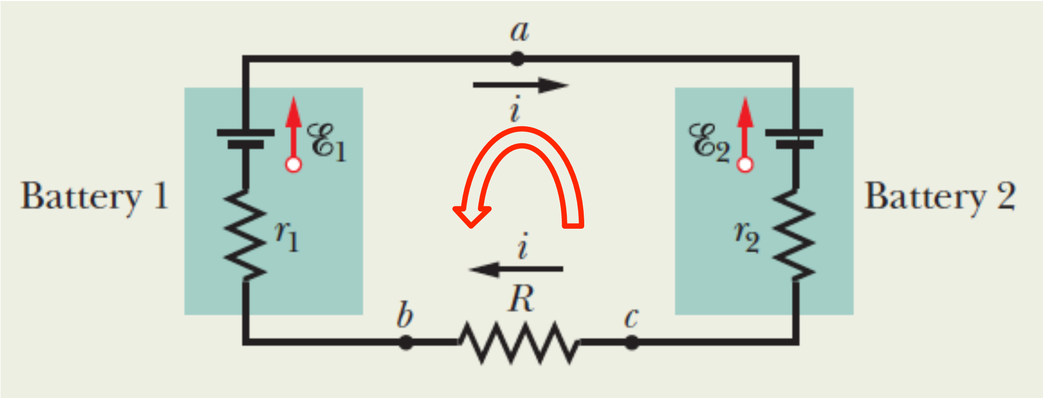
**Solution a)**

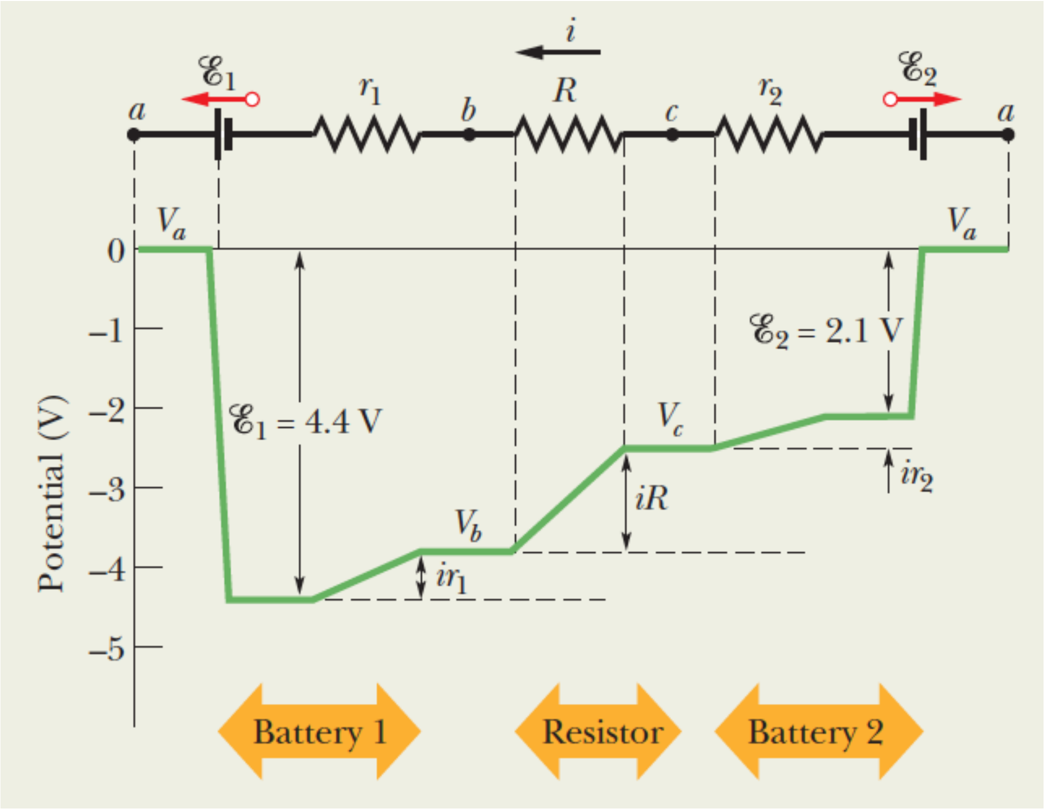



$$-\varepsilon_1 + ir_1 + iR + ir_2 + \varepsilon_2 = 0$$

$$i = \frac{\varepsilon_1 - \varepsilon_2}{R + r_1 + r_2} \approx 240mA$$

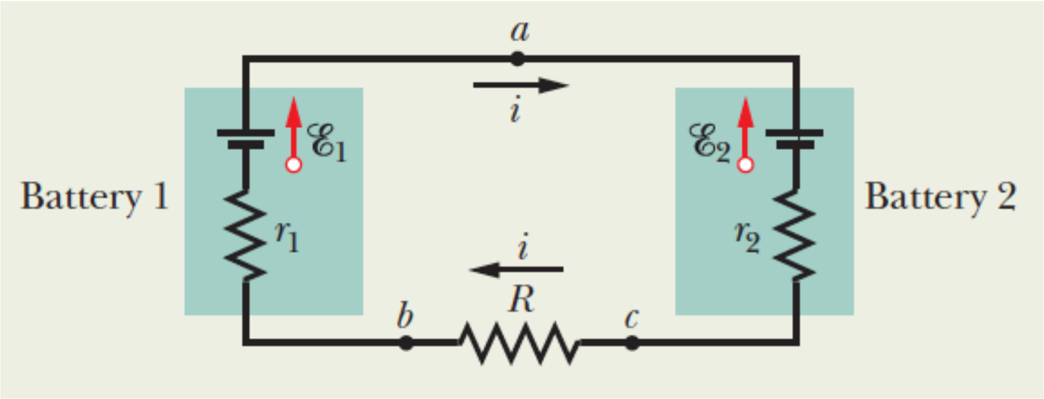
# 7.3 Kirchoff's Rules




$$-\varepsilon_1 + ir_1 + iR + ir_2 + \varepsilon_2 = 0$$

## Solution b)



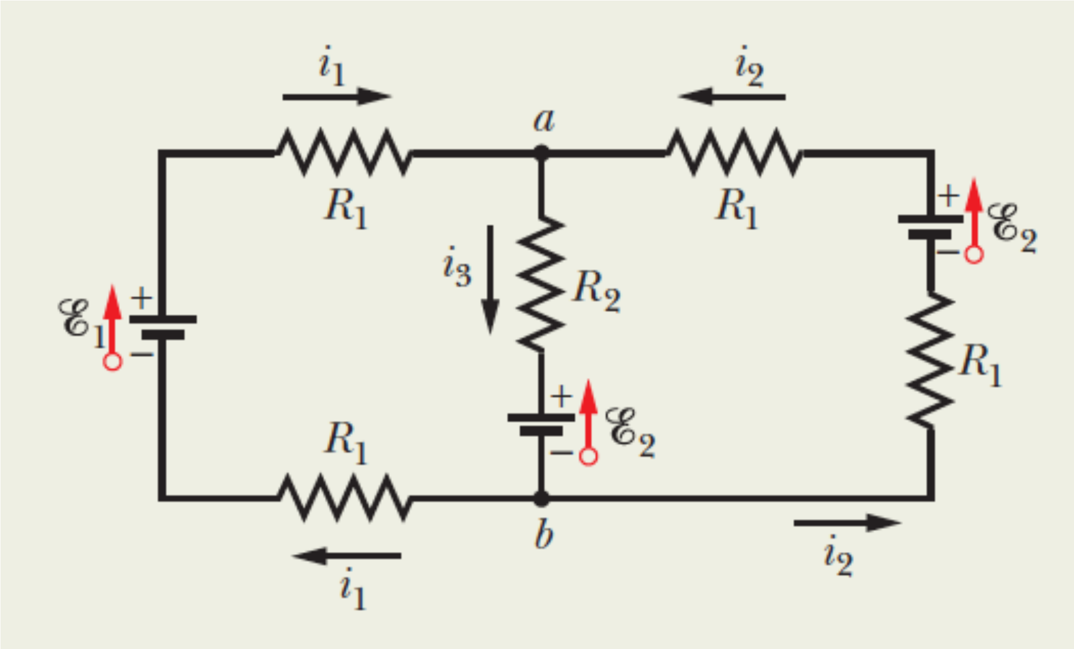

$$V_b - ir_1 + \varepsilon_1 = V_a$$

$$V_a - V_b = -ir_1 + \varepsilon_1 \approx 3.8V$$

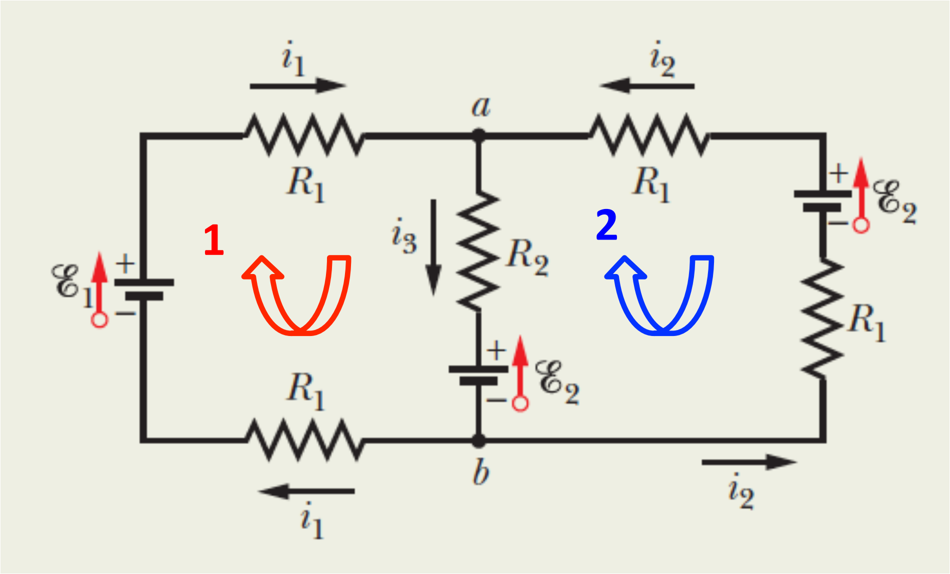
**Example:** The Fig. below shows a circuit whose elements have the following values:

$$\varepsilon_1 = 3.0V,\ \varepsilon_2 = 6.0V,$$
$$R_1 = 2.0\Omega,\ R_2 = 4.0\Omega$$

The three batteries are ideal batteries. Find the magnitude and direction of the current in each of the three branches.



## Solution:




Junction rule for point a

$$i_1 + i_2 = i_3$$

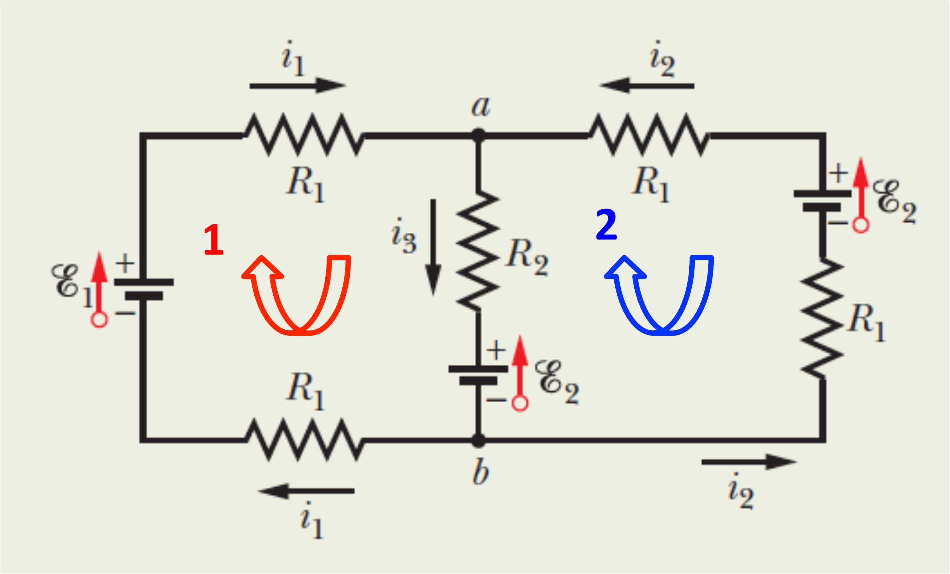
For the loop on the left side:

$$-i_1R_1 + \varepsilon_1 - i_1R_1 - i_3R_2 - \varepsilon_2 = 0$$

For the loop on the right side:

$$i_2R_1 - \varepsilon_2 + i_2R_1 + \varepsilon_2 + i_3R_2 = 0$$

**Solution:**




$$8i_1 + 4i_2 = -3$$

$$4i_1 + 8i_2 = 0$$

$$i_1 = -0.5A$$

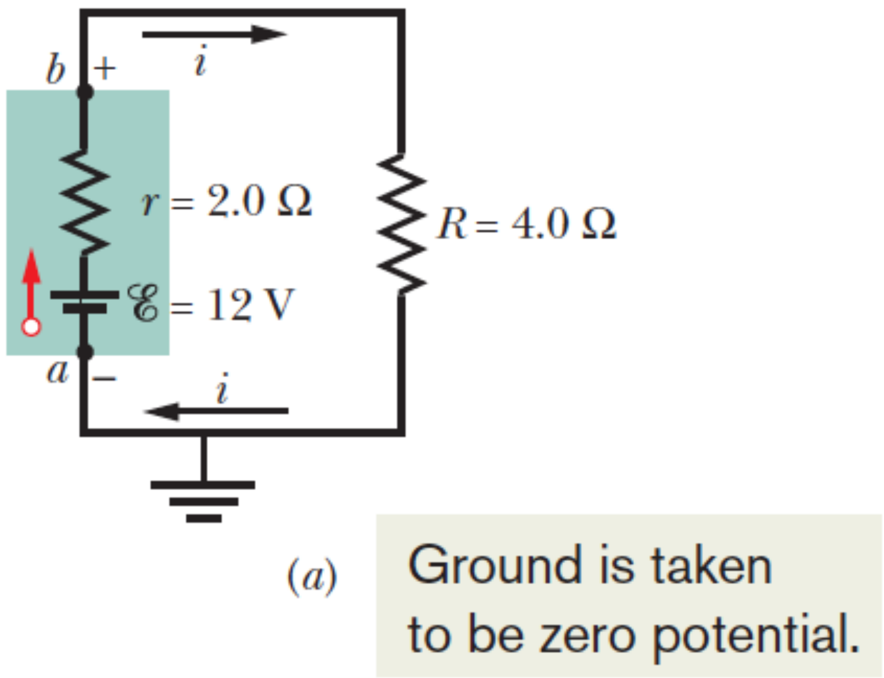
$$i_2 = 0.25A$$

$$i_3 = -0.25A$$

The minus sign signals that our arbitrary choice of direction for that current was wrong. Therefore the correct answers are:

$$i_1 = 0.5A \qquad i_2 = 0.25A \qquad i_3 = 0.25A$$

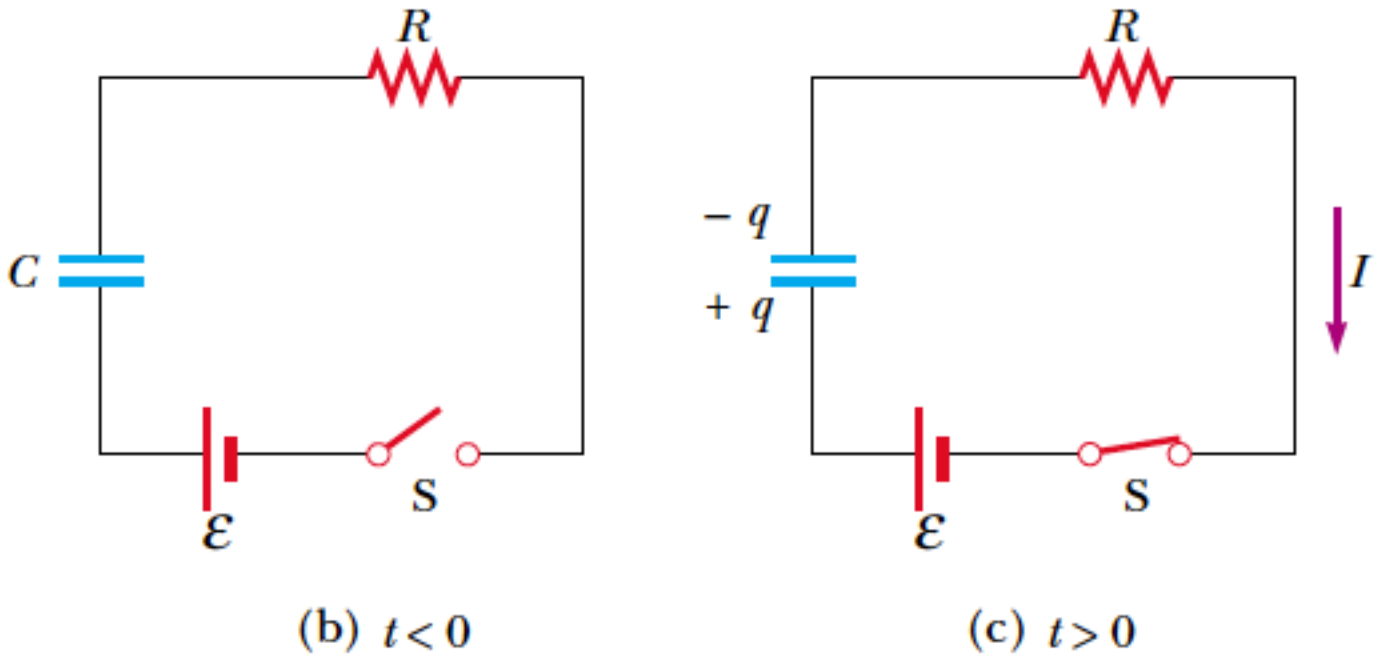
## Grounding a circuit



(a)

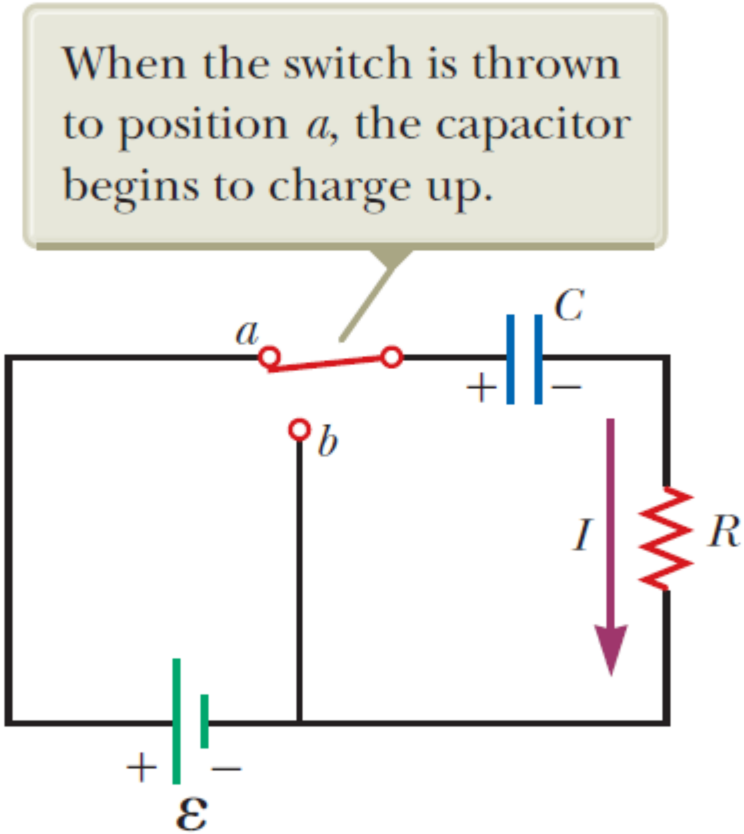
Grounding a circuit usually means connecting the circuit to a conducting path to Earth's surface. Here, such a connection means only that the potential is defined to be **zero** at the grounding point in the circuit.

## Charging a Capacitor



# 7.4 RC Circuits

## Charging a Capacitor




By applying Kirchhoff's loop rule to the circuit , we get

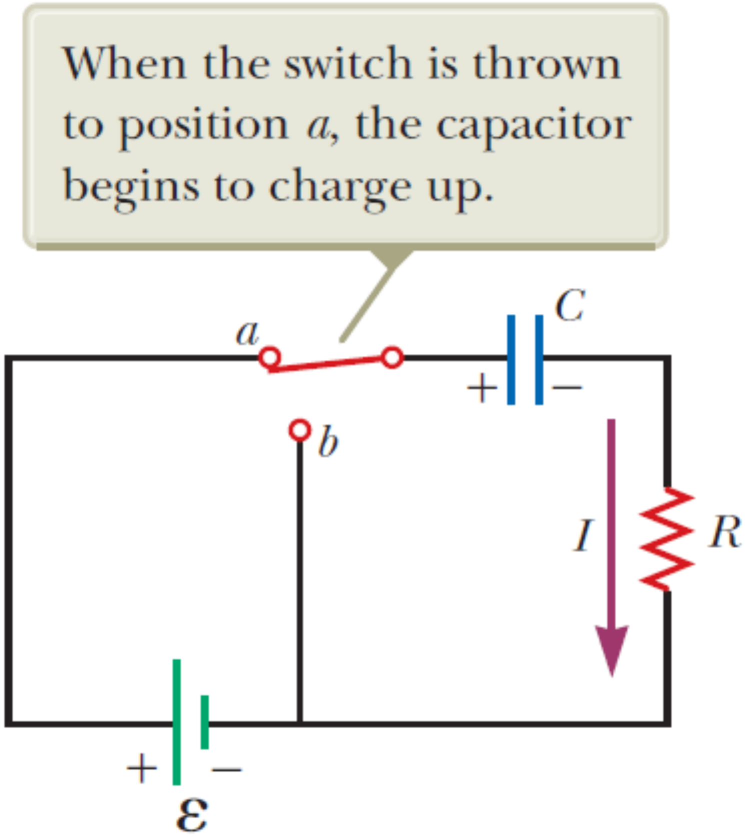
$$\varepsilon - \frac{q}{C} - iR = 0$$

By using definition of current as i=dq/dt

$$\varepsilon - \frac{q}{C} - \frac{dq}{dt}R = 0$$

$$R\frac{dq}{dt} + \frac{q}{C} = \varepsilon$$

## Charging a Capacitor




The solution to this equation is:

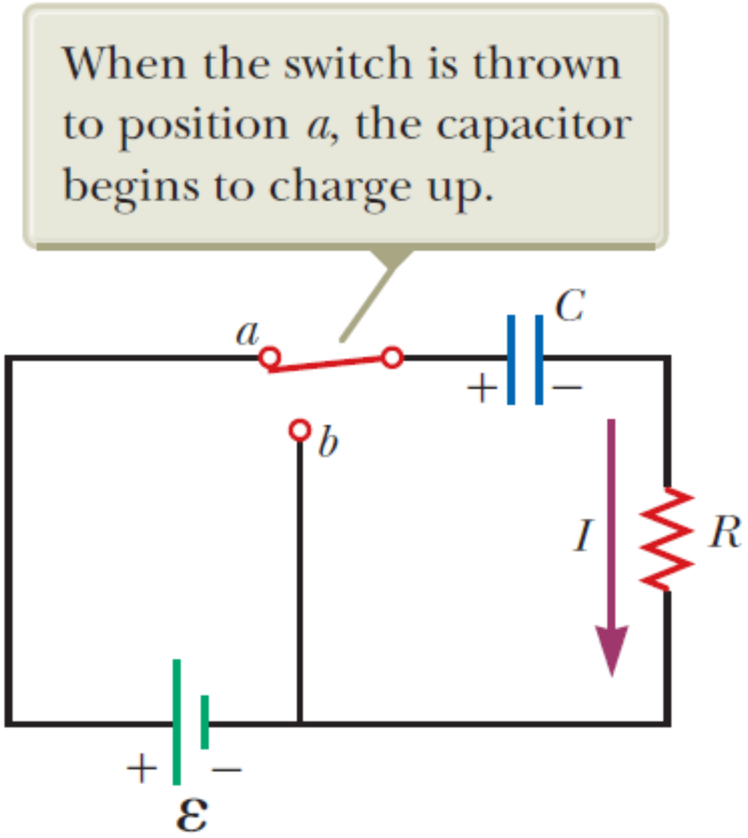
$$q(t) = C\varepsilon(1 - e^{-t/RC})$$

The derivative of q(t) is the current i(t) charging the capacitor:

$$i = \frac{dq}{dt} = \frac{\varepsilon}{R} e^{-t/RC}$$

## Charging a Capacitor

The potential difference VC(t) across the capacitor during the charging process is




$$V_C = \frac{q}{C} = \varepsilon(1 - e^{-t/RC})$$

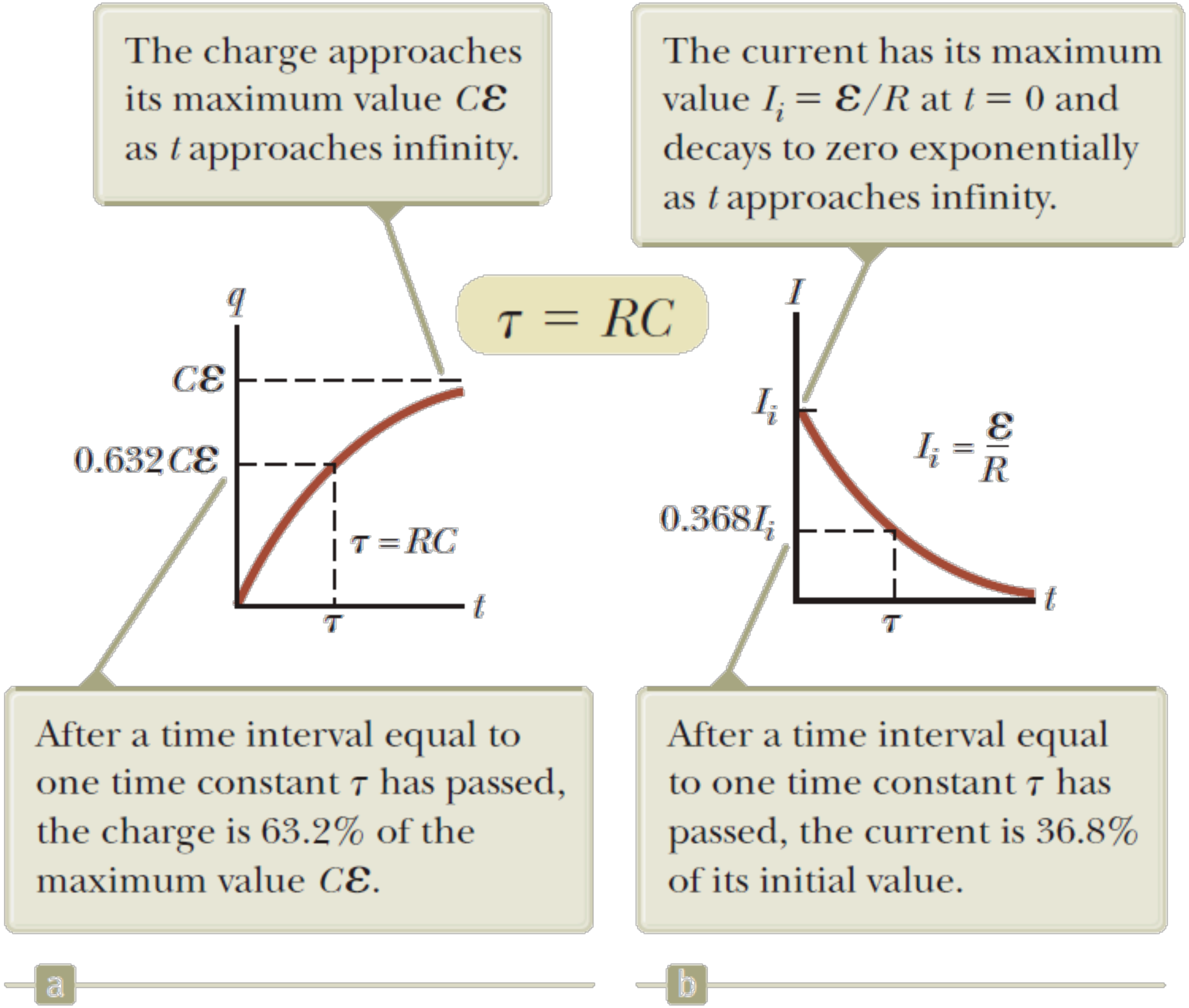
The product RC is called the capacitive time constant of the circuit and is represented with the symbol τ

$$\tau = RC$$

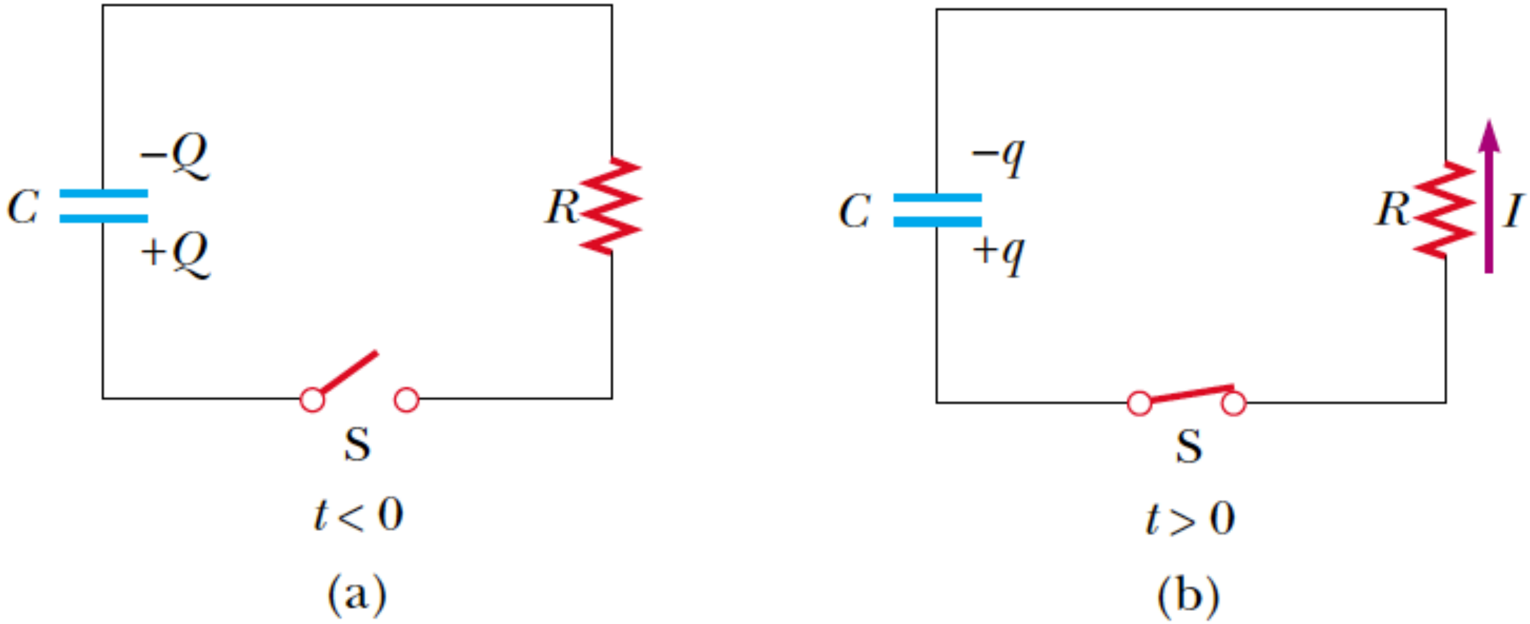
At t=τ the charge has reached to 63% of its final value Cε

# 7.4 RC Circuits

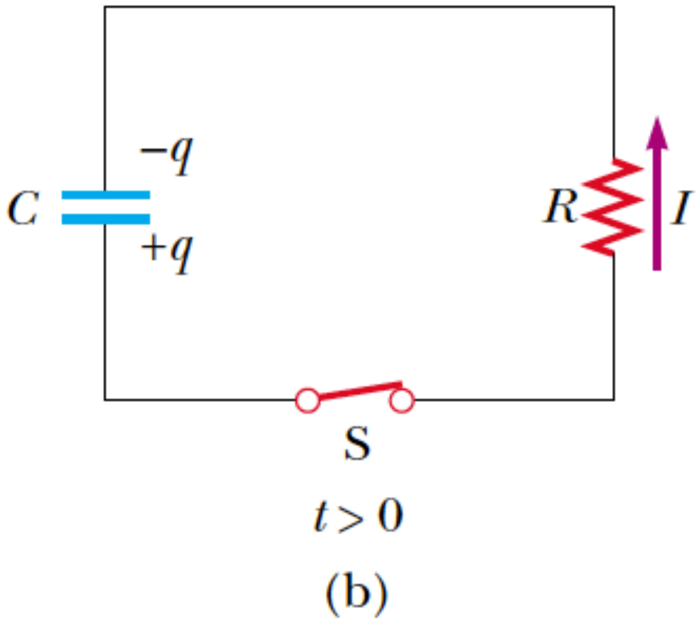
## Charging a Capacitor



## Discharging a Capacitor



## Discharging a Capacitor




By applying Kirchhoff's loop rule to the circuit , we get

$$-\frac{q}{C} + iR = 0$$

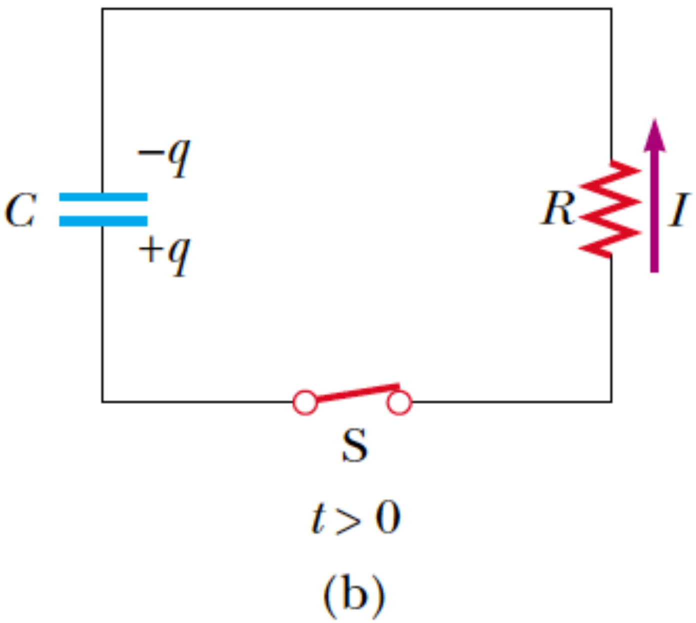
$$-\frac{q}{C} + \frac{dq}{dt}R = 0$$

The solution to this equation is:

$$q(t) = C\varepsilon e^{-t/RC} = q_0 e^{-t/RC}$$

q decreases exponentially with time, at a rate that is set by the capacitive time constant RC

## Discharging a Capacitor




The current i(t):

$$i(t) = -\frac{q_0}{RC} e^{-t/RC}$$

The current also decreases exponentially with time, at a rate set by RC

The negative sign indicates that as the capacitor discharges, the current direction is opposite its direction when the capacitor was being charged.