Announcements

1. First hour exam – Friday, February 4, 2004 – covering Chapters 22-28.

   May bring 1 8½" x 11" sheet of paper to the exam (to be turned in with your exam papers).

   The exam will be proctored by Professor G. Holzwarth.

   Practice exam available on website.

   Review sessions: Tuesday 2/1/05 at 6-7 PM

   Wednesday 2/2/05 (class time)

2. Today's topic

   Current, power, circuits

1. [HRW6 27.P.007.] A fuse in an electric circuit is a wire that is designed to melt, and thereby open the circuit, if the current exceeds a predetermined value. Suppose that the material to be used in a fuse melts when the current density rises to 410 A/cm^2. What diameter of cylindrical wire should be used to limit the current to 0.65 A?

m

4. [HRW6 27.P.026.] In Earth's lower atmosphere there are negative and positive ions, created by radioactive elements in the soil and cosmic rays from space. In a certain region, the atmospheric electric field strength is 110 V/m, directed vertically down. This field causes singly charged positive ions, 690 per cm^3, to drift downward and singly charged negative ions, 580 per cm^3, to drift upward (Fig. 27-24). The measured conductivity is $2.70 \times 10^{-14} / \Omega \cdot m$.

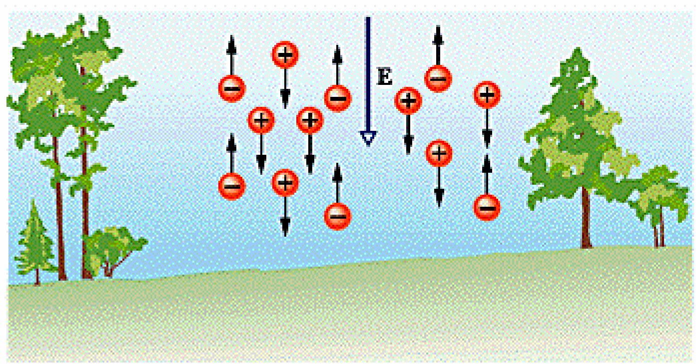


Figure 27-24.

Calculate

(a) the ion drift speed, assumed to be the same for positive and negative ions, and

[ ] cm/s

(b) the current density.

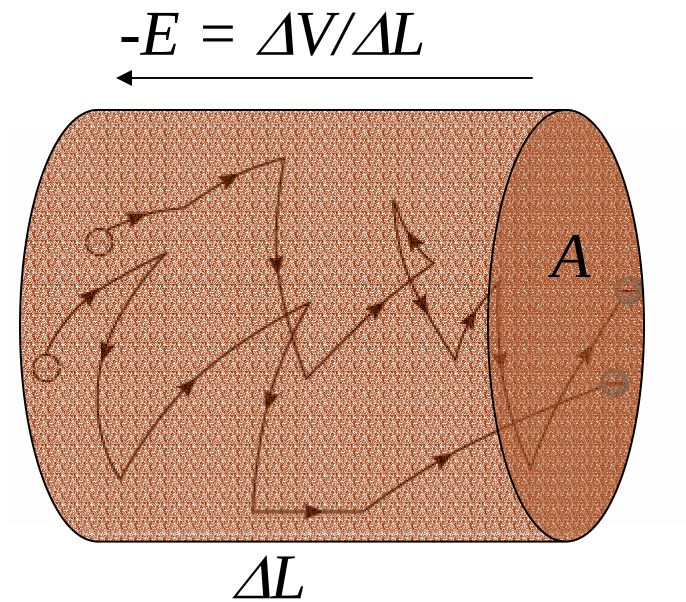
[ ] A/m^2

Electrical current in a wire

Approximately follows Ohm's law: $\Delta V = IR$

The resistance R depends on properties of the materials

$$R = \frac{m\Delta L}{q^2 n\tau A} \equiv \rho\frac{\Delta L}{A}$$



m electron mass

q electron charge

n number of electrons/volume

τ time between collisions

In general R depends on temperature T.

Electrical power associated with current in a wire

$$dU = dq\Delta V$$

$$\Rightarrow \underbrace{\frac{dU}{dt}}_{\mathscr{P}} = \frac{dq}{dt}\Delta V \equiv I\Delta V$$

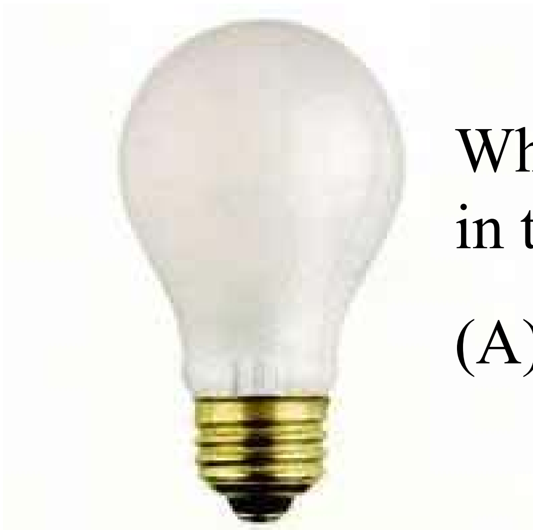
$\mathscr{P}$ (electrical power)

unit: 1 J/s = 1 Watt

$$\mathscr{P} = I\Delta V = I^2 R = \frac{(\Delta V)^2}{R}$$

➔$\mathscr{P}$ represents rate of energy transfer while current passes through wire

Consider a 60 W light bulb, connected to a 120 V voltage source.



What is the current passing through the wire in the bulb?

(A) 0.5 A   (B) 1.0 A   (C) 30 A   (D) 240 A

What is the resistance of the wire in the bulb?

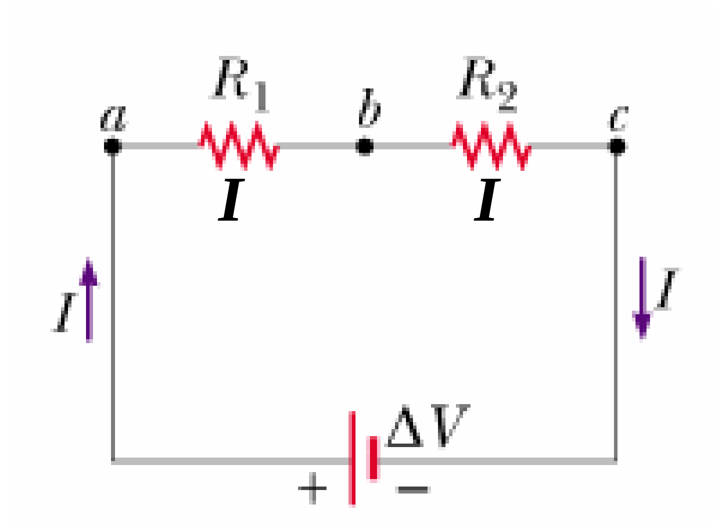
(A) 0.5 Ω   (B) 1.0 Ω (C) 30 Ω (D) 240 Ω

Online Quiz for Lecture 7
Electrical current -- Jan. 28, 2005

Suppose that you connect a light bulb (either 30-W or 60-W) to a 120 V voltage source.

1. What is the resistance (in Ω) in the 30-W bulb?
   (a) 0.25 (b) 4 (c) 480 (d) 3600
2. What is the current (in Amps) in the 30-W bulb?
   (a) 0.25 (b) 4 (c) 480 (d) 3600
3. What is the resistance (in Ω) in the 60-W bulb?
   (a) 0.5 (b) 2 (c) 240 (d) 7200
4. What is the current (in Amps) in the 60-W bulb?
   (a) 0.5 (b) 2 (c) 240 (d) 7200

Connecting resistors in series:



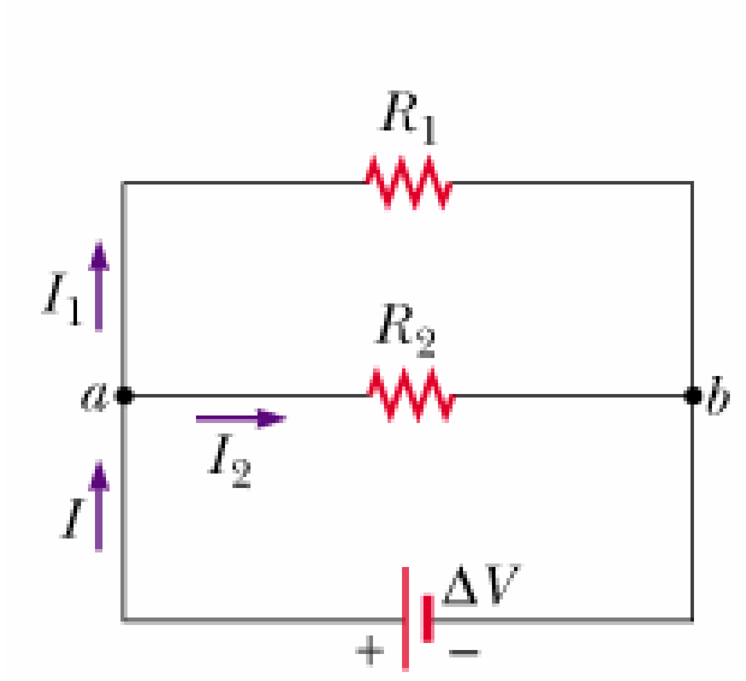
The same current I passes through both resistors R_1 and R_2.

$$\Delta V = I\,R_1 + I\,R_2$$
$$= I\,(R_1 + R_2)$$

➔For resistors connected in series:

$$R_{eq} = \sum_i R_i$$

Resistors connect in parallel



The same voltage ΔV passes through each resistor:

$$\Delta V = I_1 R_1 = I_2 R_2$$

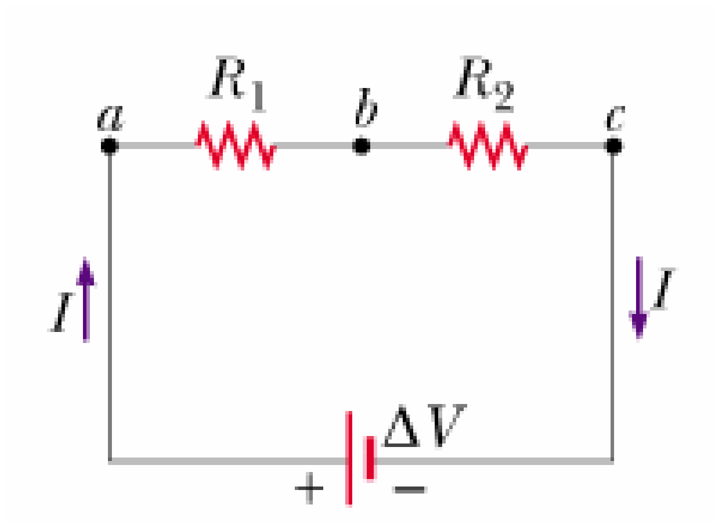
$$I = I_1 + I_2$$

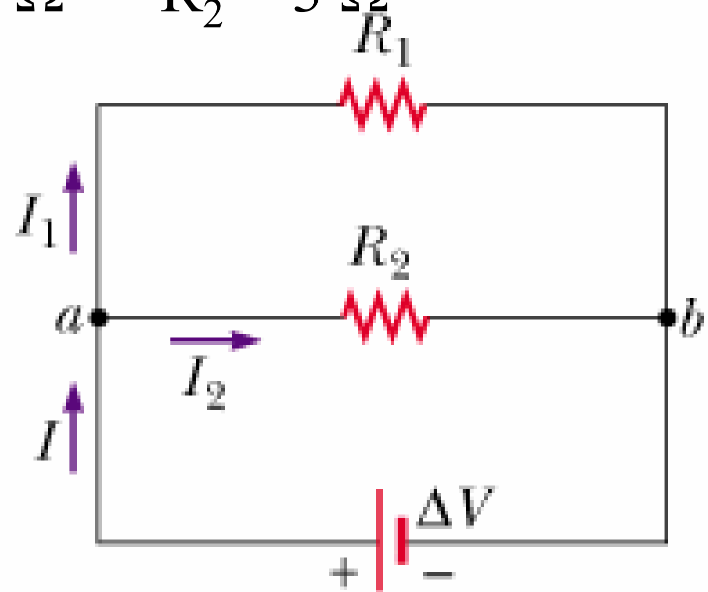
$$\Delta V = I R_{eq}$$

➔For resistors connected in parallel:

$$\frac{1}{R_{eq}} = \sum_i \frac{1}{R_i}$$

Example: $\Delta V = 100$ V $\quad R_1 = 2\ \Omega \quad R_2 = 3\ \Omega$





$$R_{eq} = R_1 + R_2 = 2\Omega + 3\Omega = 5\Omega$$

$$I = \frac{\Delta V}{R_{eq}} = \frac{100V}{5\Omega} = 20A$$

$$V_1 = IR_1 = 40V \qquad V_2 = IR_2 = 60V$$

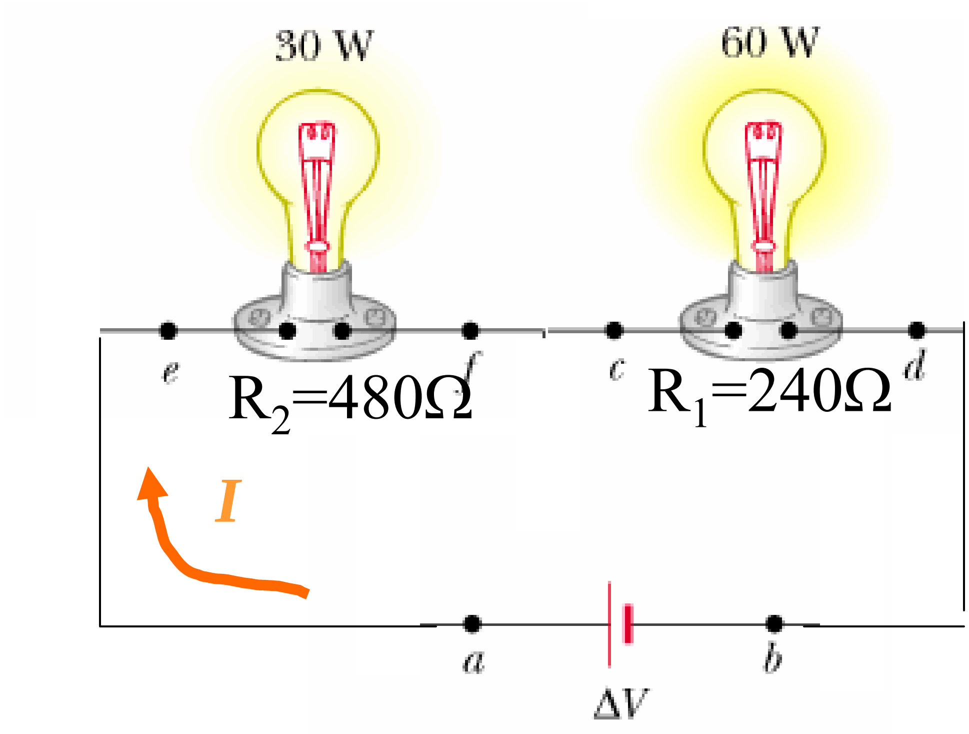
$$\mathcal{P} = I_1V_1 + I_2V_2 = 2000W$$

$$V_1 = I_1R_1 = I_2R_2 = V$$

$$I_1 = \frac{V}{R_1} = \frac{100V}{2\Omega} = 50A$$

$$I_2 = \frac{V}{R_2} = \frac{100V}{3\Omega} = 33.333A$$

$$\mathcal{P} = I_1V_1 + I_2V_2 = 8333.33333W$$



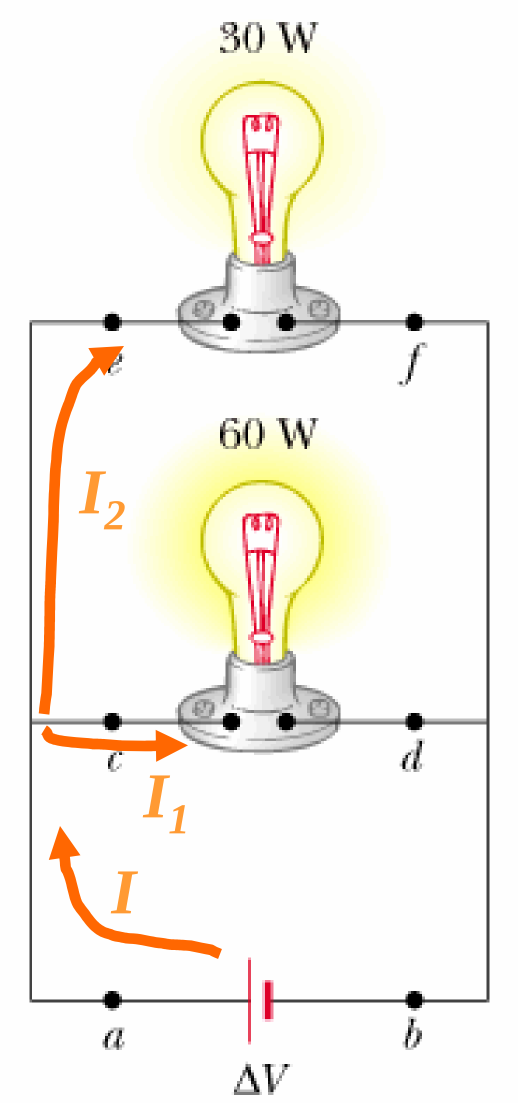
$$\Delta V = I\,(R_1 + R_2)$$

$$I = 0.167\ \text{A}$$

$$\mathscr{P}_2 = 13.33\ \text{W}$$

$$\mathscr{P}_1 = 6.67\ \text{W}$$

Consider the circuit shown on the left. How much current is running in each light bulb when ΔV = 120 V? (Note: the power rating of each bulb is valid only when they are connected to a 120 V voltage source.)



$$I_2 = \frac{\mathcal{P}_2}{\Delta V} = 0.25A \qquad R_2 = \frac{(\Delta V)^2}{\mathcal{P}_2} = 480\Omega$$

$$I_1 = \frac{\mathcal{P}_1}{\Delta V} = 0.5A \qquad R_1 = \frac{(\Delta V)^2}{\mathcal{P}_1} = 240\Omega$$

$$I = I_1 + I_2 = 0.75A$$

Peer instruction question

Suppose you connect two devices, each with a resistance of 100 Ω in ***parallel*** to a 120 V voltage source. What is the total current in the circuit?

(A) 0.6 A (B) 1.2 A (C) 2.4 A (D) 4.8 A

Suppose you connect two devices, each with a resistance of 100 Ω in ***series*** to a 120 V voltage source. What is the total current in the circuit?

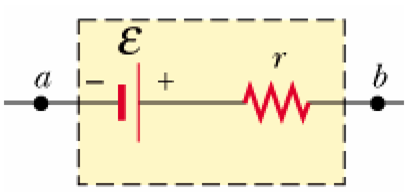
(A) 0.6 A (B) 1.2 A (C) 2.4 A (D) 4.8 A

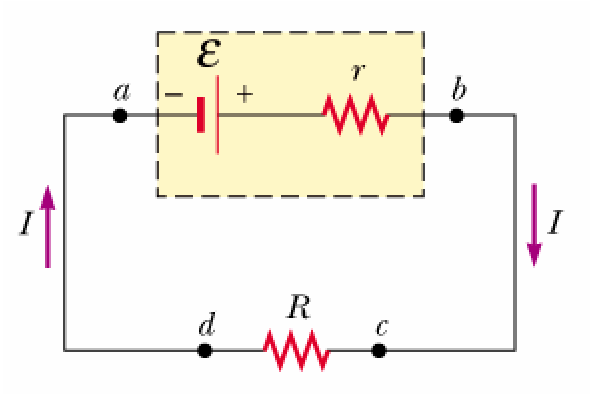
Voltage sources

- •Batteries (chemical reactions)
- •Solar cells (conversion of solar energy to voltage output)
- •Generators (conversion of mechanical energy to voltage output)

General terminology – "electromotive force" – emf, $\mathcal{E}$

Real emf's often have energy losses during operation so that the ideal voltage $\mathcal{E}$ is reduced. This energy loss can be modeled by an internal resistance *r* represented by the equivalent circuit:





In this case the current is then determined by

$$\mathcal{E} = (r + R)I$$

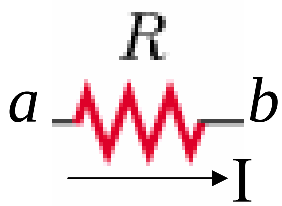
$$I = \frac{\mathcal{E}}{r + R}$$

Analysis of DC circuits:

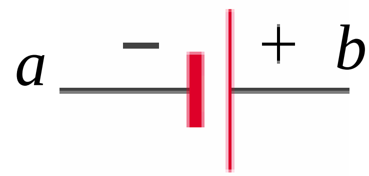
Elements:

a *b*

wire – $V_{ab} \approx 0$



resistor – $V_{ab} = -IR$



emf – $V_{ab} = \mathcal{E}$

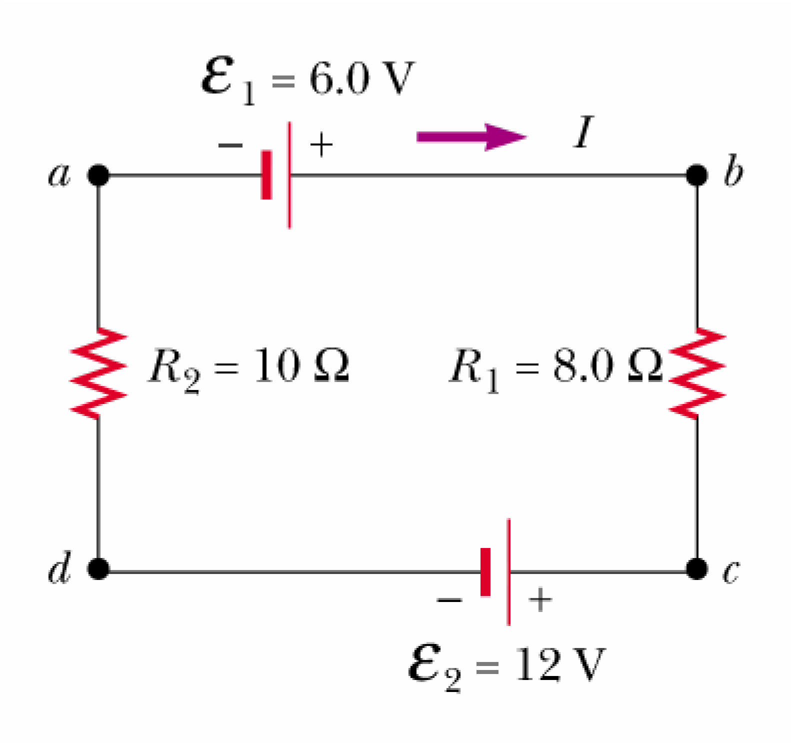
The principles:

Kirchhoff's rules

At any wire function: $\sum I_{in} = \sum I_{out}$

For any closed wire loop: $\sum \Delta V = 0$

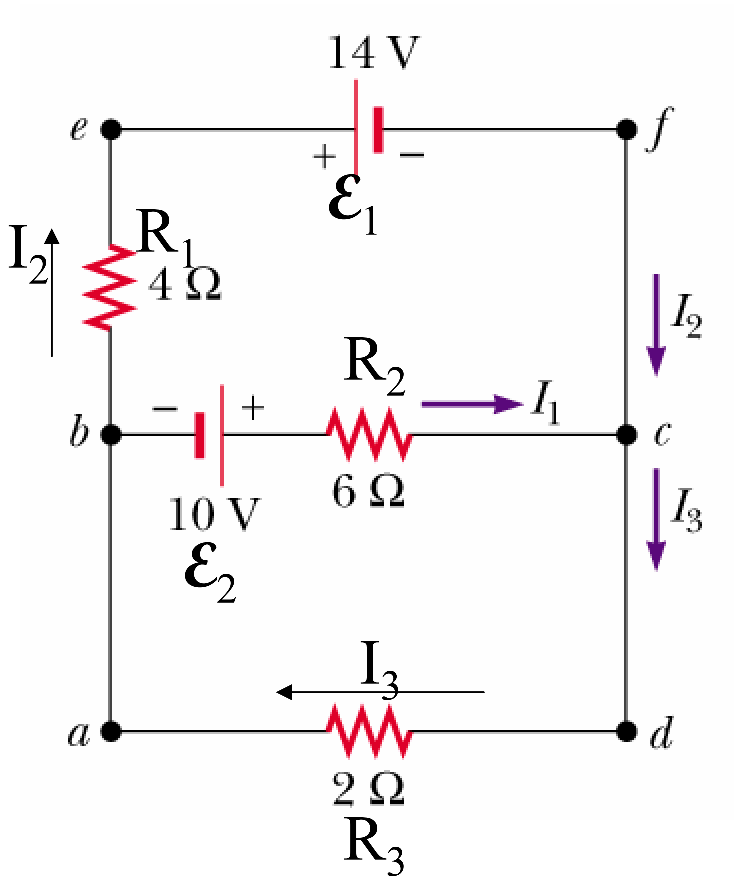
Example:



$$\mathcal{E}_1 - \mathrm{IR}_1 + (-\mathcal{E}_2) - \mathrm{IR}_2 = 0$$

$$I = \frac{\mathcal{E}_1 - \mathcal{E}_2}{R_1 + R_2} = -0.33A$$

Example:



$$-\mathcal{E}_1+I_1R_2-\mathcal{E}_2-I_2R_1=0$$

$$\mathcal{E}_2-I_1R_2-I_3R_3=0$$

$$I_1+I_2=I_3$$

$$I_1 = 2\ A$$

$$I_2 = -3A$$

$$I_3 = -\ 1\ A$$