

Kirchhoff's Laws

by

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P4.10D Discriminate between voltage, resistance, and current as they apply to an electric circuit.

P4.10i Compare the energy used in one day by common household appliances (e.g., refrigerator, lamps, hair dryer, toaster, televisions, music players).

P4.10j Explain the difference between electric power and electric energy as used in bills from an electric company.

Items;

- 1- Kirchhoff's Voltage Law (Loop Rule)
- 2- Kirchhoff's Current Law (Junction Rule)

Conservation of Electrical Energy

Conservation of Energy:

As electrons move through an electric circuit, they gain energy in sources and lose energy in loads, but the total energy gained in one trip through a circuit is equal to the total energy lost.

Conservation of charge:

Electric charge is neither created nor lost in an electric circuit, nor does it accumulate at any point in the circuit.

Kirchhoff's Laws of Electric Circuits

There are many circuits in which more than one device is connected to a voltage (electric potential) source. The two major types are:

- a) Series circuits
- b) Parallel circuits.

Gustav Robert Kirchhoff is a German Physicist (1824 - 1887). He described the conservation of energy and conservation of charges in terms of quantities easily measurable in electric circuits leading to what is known now as Kirchhoff's Voltage Law (KVL) and Kirchhoff's Current Law (KCL).

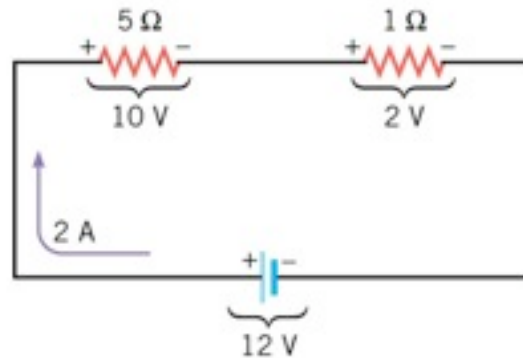
Kirchhoff's Voltage Law (Loop Rule)

Around any complete path through an electric circuit (closed circuit loop), the sum of the increases in electric potential is equal to the sum of the decreases in electric potential. Therefore, the sum over all of the changes in potential is zero.

Kirchhoff's Voltage Law

$$V = V_1 + V_2 + V_3 + \text{etc}$$

Example 1: Closed Circuit Loop



Potential rises = Potential drops

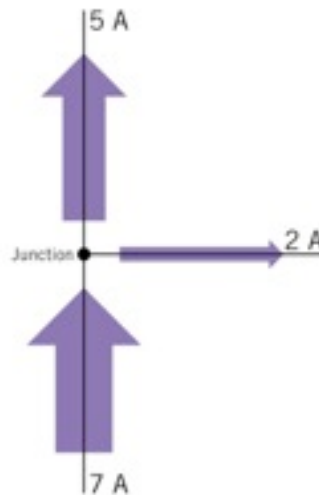
$$12 \text{ V} = 10 \text{ V} + 2 \text{ V}$$

Kirchhoff's Current Law (Junction Rule)

At any junction point in an electric circuit (I), the total electric current into the junction is equal to the total electric current out of the junction.

| |
|------------------------------------|
| Kirchhoff's Current Law |
| $I = I_1 + I_2 + I_3 + \text{etc}$ |

Example 2: *Junction Point in Electric Circuit*



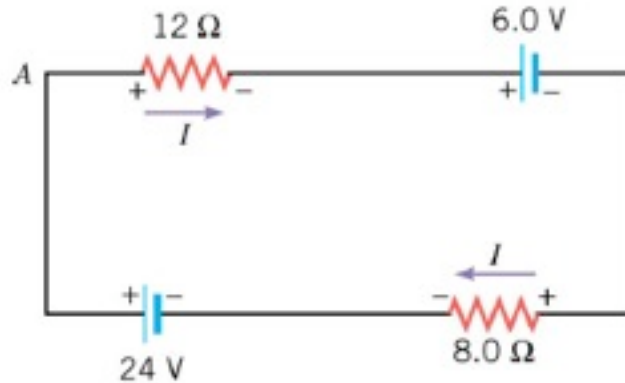
sum of into currents = sum of currents out
 $7\text{ A} = 2\text{ A} + 5\text{ A}$

Strategy in Applying Kirchhoff's Rules:

- 1- Draw the current in each branch of the circuit. Choose any direction. If your choice is incorrect, the value obtained for the current will turn out to be a negative number.
- 2- Mark each resistor with a + at one end and a - at the other end in a way that is consistent with your choice for the current direction in step 1. For batteries, the signs will be the usual + for higher potential and – for lower potential.
- 3- Apply the junction rule and the loop rule to the circuit and obtain independent equations.
- 4- Solve these equations simultaneously for the unknown variables.

Example 3: *Kirchhoff's Loop Rule: Current in a Circuit;*

Determine the current (I) in the circuit. The circuit has two resistors R ($12\ \Omega$, $8\ \Omega$)



The current is moving in a clockwise loop.

Ohm's Law: $V = I R$

According to Kirchhoff's Loop rule:

Potential rises = Potential drops

$$24 = 6.0 + (I \times 12) + (I \times 8)$$

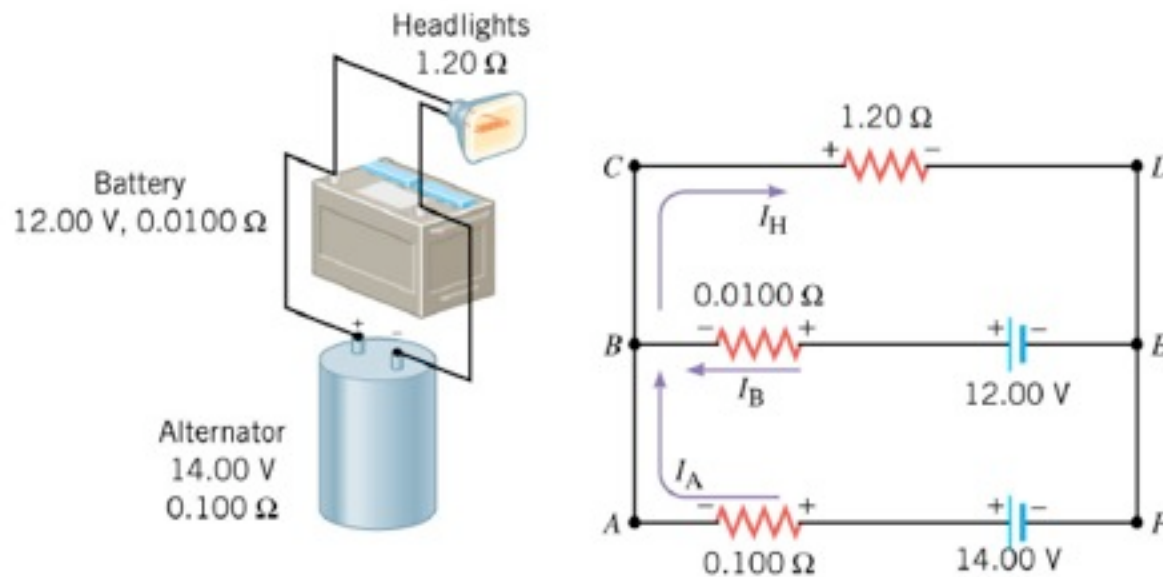
$$24 - 6 = I \times 20$$

$$18 = I \times 20$$

$$I = 18 / 20 = 0.90\ \text{A}$$

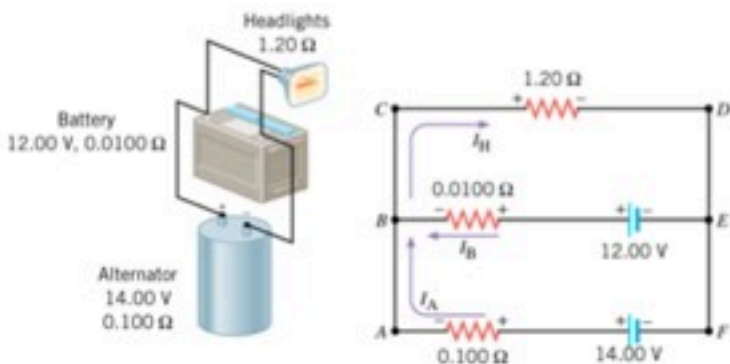
Example 4: A Car's Headlight;

A car's headlight is connected to the battery which is charged by the alternator as shown in the figure and circuit diagram. Different currents pass through the headlight, battery and alternator.



Kirchhoff's loop rule can be applied to the loops ABEF and BCDE In the clockwise direction.

Kirchhoff's current rule can be applied to junction B ($I_A + I_B = I_H$).



$$r_A = 0.100 \, \Omega \quad r_B = 0.010 \, \Omega \quad R_H = 1.20 \, \Omega$$

Apply the Junction rule at B:

$$I_A + I_B = I_H \quad \text{Eq. 1}$$

Apply the Loop rule for ABEF and BCDE
In the clockwise direction:

$$\text{ABEF: } 14 - I_A r_A + I_B r_B - 12 = 0 \Rightarrow I_A = \frac{2 + I_B r_B}{r_A} \quad \text{Eq. 2}$$

$$\text{BCDE: } 12 - I_B r_B - I_H R_H = 0 \Rightarrow I_H = \frac{12 - I_B r_B}{R_H} \quad \text{Eq. 3}$$

Put Eq. 2 and Eq. 3 into Eq. 1, solve for I_B . Then use Eq. 2 and Eq. 3 to get I_A and I_H :

$$\frac{2 + I_B r_B}{r_A} + I_B = \frac{12 - I_B r_B}{R_H}$$

$$\Rightarrow I_B = \frac{12r_A - 2R_H}{r_B R_H + r_A R_H + r_A r_B} = -9.02 \, \text{A} \quad I_A = 19.10 \, \text{A} \quad I_H = 10.08 \, \text{A}$$

\swarrow I_B flows in **opposite** direction of diagram

References:

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Physics 1200 Lecture Slides: Dr. Thomas Humanic, Professor of Physics, Ohio State University, *2013-2014 and Current*. www.physics.ohio-state.edu/~humanic/

2) Cutnell, J. D. & Johnson, K. W. (1998). *Cutnell & Johnson Physics, Fourth Edition*. New York: John Wiley & Sons, Inc.

The edition was dedicated to the memory of Stella Kupferberg, Director of the Photo Department: “We miss you, Stella, and shall always remember that a well-chosen photograph should speak for itself, without the need for a lengthy explanation”

- 3) Martindale, D. G. & Heath, R. W. & Konrad, W. W. & Macnaughton, R. R. & Carle, M. A. (1992). *Heath Physics*. Lexington: D.C. Heath and Company
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