

Electrical Equations

Ohm's law is the most basic rule describing the behavior of an electrical circuit. It describes the relationship between voltage, current and resistance. *Figure 213.1* shows a handy method of remembering Ohm's law. Ohm's law is used to find the missing quantity when the other two quantities are known. For example, assume that the voltage of a circuit is 24 volts and the current flowing in the circuit wire is 2 amperes. Ohm's law can be used to calculate the resistance of the circuit in ohms. Resistance for this example is 24 volts divided by 2 amperes to give 12 ohms. Here is how to use *Figure 213.1*. Resistance is usually represented with the letter **R**, current the letter **I**, and voltage the letter **E**.

1. Cover up the quantity you want to calculate such as volts, amperes or ohms.
2. If the remaining two quantities are side by side, then multiply them together to get voltage using *Equation 213.1*. (Amperes times Ohms equals Volts)
3. If one quantity is above the other, then divide the bottom one into the top one using *Equation 213.2* or *Equation 213.3*. (Volts divided by Amperes equals Ohms or Volts divided by Ohms equals Amperes)

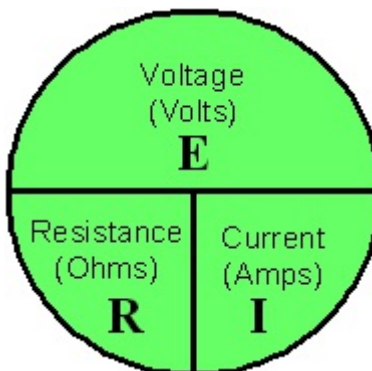


Figure 213.1 Use this diagram to remember how to determine the missing quantity when the other two are known.

$$\text{Voltage}(E) = I \times R = \text{Amps} \times \text{Ohms} = \text{Volts}(E) \quad \text{Eq. 213.1}$$

$$\text{Current}(I) = \frac{\text{Volts}}{\text{Ohms}} = \frac{E}{R} = \text{Amps}(I) \quad \text{Eq. 213.2}$$

$$R = \frac{\text{Volts}}{\text{Amps}} = \frac{E}{I} = \text{Ohms}(R) \quad \text{Eq. 213.3}$$

The following example will help to illustrate the practical way in which Ohm's law can be used. Assume we want to find out how much voltage drop occurs along a wire with a resistance of 2 ohms when there is 15 amperes flowing through the wire. This is illustrated in *Figure 213.2*. We know the current in amperes and the resistance is ohms. Refer to *Figure 213.3* and note that the desired quantity, voltage, is covered up. The current and resistance are side by side, therefore, they are multiplied to get the voltage using *Equation 213.1*. The voltage drop along the wire is 30 volts.

$$\text{Voltage} = \text{Amps} \times \text{Ohms} = 15 \text{ A} \times 2 \text{ ohm} = 30 \text{ V}$$

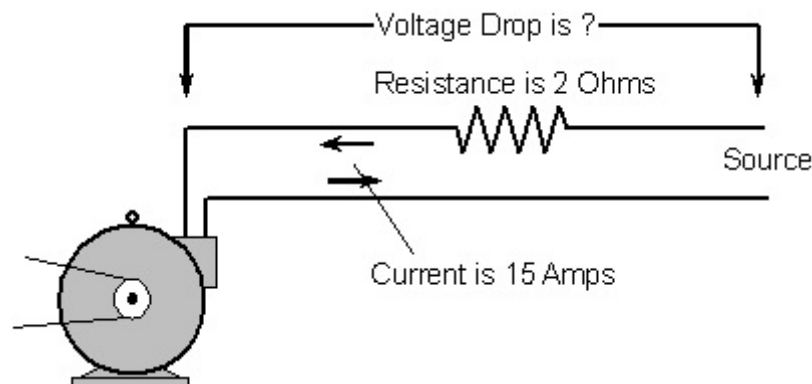


Figure 213.2 The current flowing to the load is 15 amperes and the resistance of the wire is 2 ohms.

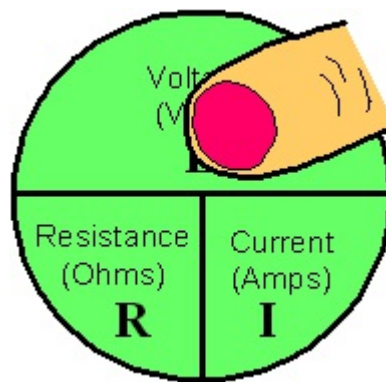


Figure 213.3 Cover up volts to determine the amperes times ohms will give volts.

Electrical Power: The power equation is the relationship between voltage, current and watts. This is a very useful equation especially in the electrical trade. *Figure 213.4* can be used to remember how to determine the missing information when two of the quantities are known. *Figure 213.4* is a special case of the power equation which only applies to direct current loads and certain alternating current loads such as incandescent light bulbs and electric heaters (resistive loads). This equation as shown in *Figure 213.4*, does not work for loads such as alternating current motors and many other alternating current loads. Here is how to use *Figure 213.4*. For a detailed discussion of the use of the power equation in alternating current circuits see *Tech Note 223*. For this discussion we will not consider the other quantity in the power equation called the power factor.

1. Cover up the quantity you want to calculate such as volts, amperes or watts.
2. If the remaining two quantities are side by side, then multiply them together to get wattage as shown in *Equation 213.4*. (Volts times Amps equals Watts)
3. If one quantity is above the other, then divide the bottom one into the top one using either *Equation 213.5* or *Equation 213.6*. (Watts divided by Amps equals Volts or Watts divided by Volts equals Amps)

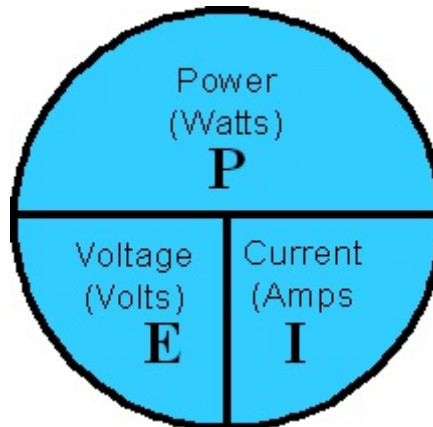


Figure 213.4 Use this diagram to remember how to determine the missing quantity when the other two are known. (A fourth quantity called power factor must be included in most alternating current power calculations.)

$$\text{Power}(P) = \text{Volts} \times \text{Amps} = E \times I = \text{Watt}(P) \qquad \text{Eq. 213.4}$$

$$\text{Current}(I) = \frac{\text{Watts}}{\text{Volts}} = \frac{P}{E} = \text{Amps}(I) \qquad \text{Eq. 213.5}$$

$$\text{Volts}(E) = \frac{\text{Watts}}{\text{Amps}} = \frac{P}{I} = \text{Volts}(E) \qquad \text{Eq. 213.6}$$

The following example will help to illustrate the practical way in which the power equation can be used. Assume we want to find out how many 150 watt incandescent light bulbs we can have on a 120 volt circuit. In order to answer this question it is necessary to determine the number of amperes drawn by one 150 watt light bulb. This is where we can use the power equation.

We know the wattage of this light bulb and the voltage of the circuit. What we want to find out is the current drawn by each light bulb. Cover up amperes in the equation of *Figure 213.4* and note that watts over volts is showing (*Equation 213.5*), as illustrated in *Figure 213.5*. To determine the amperes for the light bulb, divide 150 watts by 120 volts to get 1.25 amperes.

$$\text{Amperes} = \frac{\text{Watts}}{\text{Volts}} = \frac{150 \text{ W}}{120 \text{ V}} = 1.25 \text{ A}$$

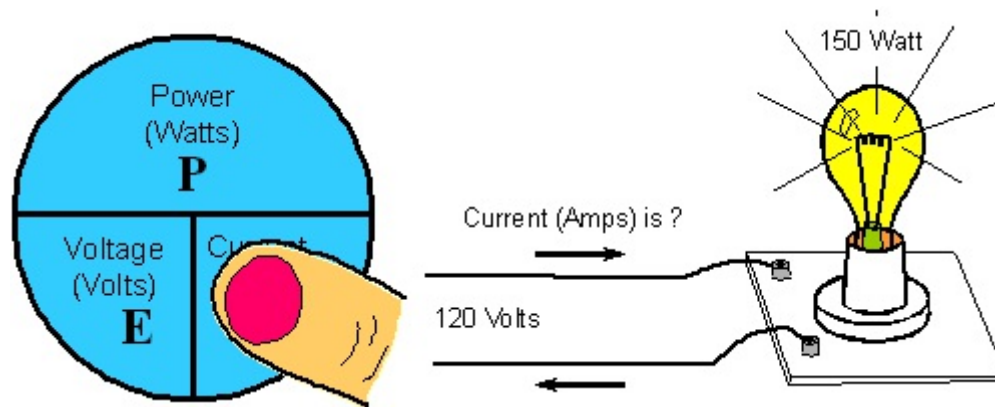


Figure 213.5 Cover up amperes and watts divided by volts will amperes.

Note: The customary symbol used by scientists and engineers for voltage is (E), current is (I) and resistance is (R). In the case of alternating current circuits with capacitance and or inductance in the circuit an additional factor called power factor (pf) must be applied to the power equation (see *TN 204*). For single-phase ac circuits the power equation is $P = E \times I \times \text{pf}$. In the case of a three-phase ac circuit the power equation is $P = 1.73 \times E \times I \times \text{pf}$. (For a discussion of three-phase electrical systems see *Tech Note 220*.)

Voltage Divider Equation: When multiple resistors are connected in series the voltage divider rule can be used to determine the voltage across one of the resistors provided the source voltage of the circuit is known. This is based on a fundamental law of electrical circuits called the Kirchhoff voltage law. In a series circuit the sum of the voltages across each resistor is equal to the source voltage of the circuit. This is *Equation 213.7* and is illustrated in *Figure 213.6*.

$$E_T = E_1 + E_2$$

Eq. 213.7

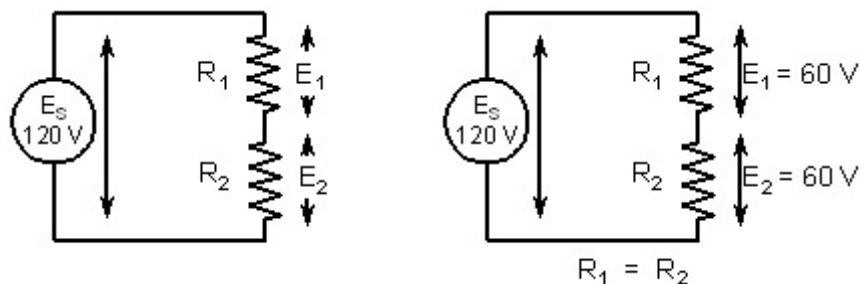


Figure 213.6 Kirchhoff voltage law states that the voltages across each element of a series circuit must be equal to the total source voltage of the circuit.

Example: If there are two resistors in a series circuit, R_1 and R_2 , both of which have the same value, each resistor will have the same voltage across it which will be half of the source voltage as shown in *Figure 213.6*.

Because of the **Kirchhoff voltage law**, if the source voltage is known and the value of each resistor is known, the voltage across each resistor can be determined by proportions. The voltage across the resistor with the largest value will have a higher resistance across it than the resistor with the smaller value. Illustrated in *Figure 213.7* the value of the voltage across each resistor can be calculated using the voltage divider equation as show in *Equation 213.8*.

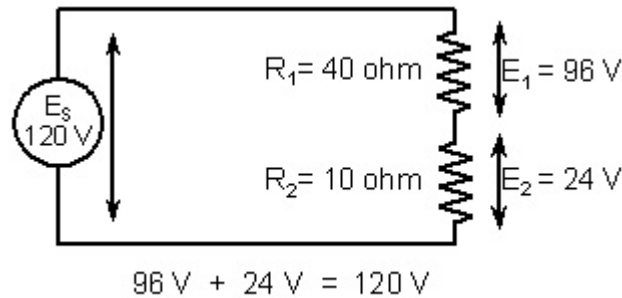


Figure 213.7 The resistor with the larger value will have the greater voltage across it and the two voltages will sum to the value of the source voltage of the circuit. This is Kirchhoff's voltage law.

The voltage divider equation can be used to determine the voltage across any resistor of a series circuit if the values of the resistors are known and the value of the source voltage is known. Equation 213.8 is the voltage divider equation.

$$E_1 = \frac{R_1}{R_1 + R_2} \times E_s \tag{Eq. 213.8}$$

The values of the voltage across each resistor of Figure 213.7 are determined using the voltage divider equation. There are other methods of determining the voltage across each resistor, but using the voltage divider equation is the most useful method.

$$E_1 = \frac{40\Omega}{10\Omega + 40\Omega} \times 120V = 96V \quad E_2 = \frac{10\Omega}{10\Omega + 40\Omega} \times 120V = 24V$$

Current Divider Equation: The current divider equation shown here is for two resistors that are connected in parallel, the value of each resistor is known, and the total current flowing through the resistors is known. The current divider equation is based on the **Kirchhoff current law**. The sum of the currents flowing through each resistor must be equal to the total current. This is illustrated in **Figure 213.8**. The current divider equation is shown in Figure 213.8 as well as Equation 213.9.

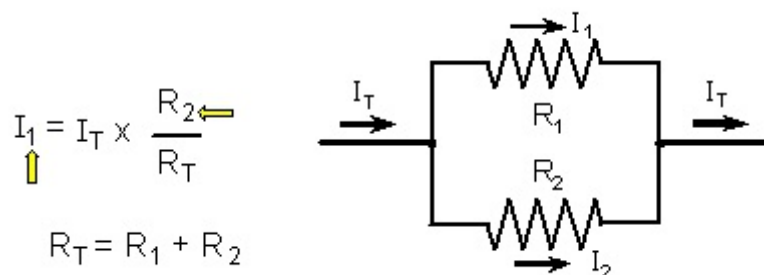


Figure 213.8 With two resistors in parallel the total current will divide with the larger current flowing through the resistor with the smaller resistance.

$$I_1 = I_T \times \frac{R_2}{R_T} \qquad I_2 = I_T \times \frac{R_1}{R_T} \qquad \text{Eq. 213.9}$$

Example: For this current divider example, resistor R_1 has a value of 18 ohms, resistor R_2 has a value of 6 ohms and the total current is 12 amperes. Take a moment and think which resistor will have the greater current. To determine the current through R_1 use resistor R_2 and the total resistance. To determine the current through R_2 use resistor R_1 and the total resistance. The calculations are shown in *Figure 213.9*.

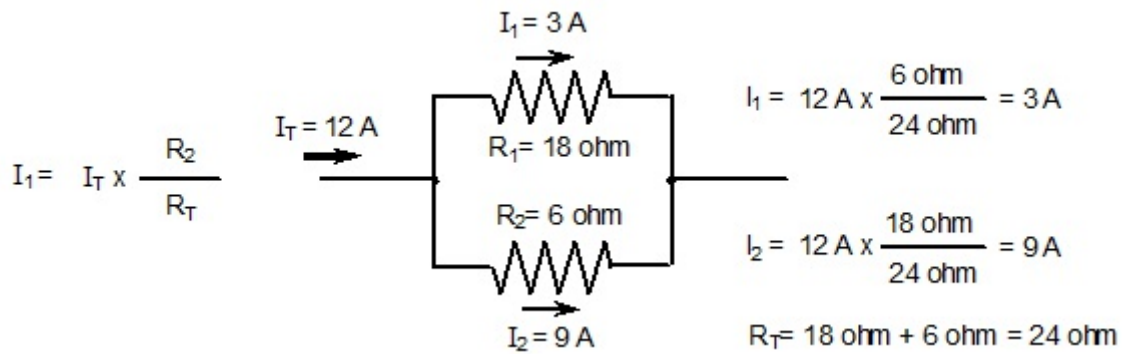


Figure 213.9 When current divides into two branches the most current will flow through the branch with the least resistance.