UNIT
1

Electrician's Math and Basic Electrical Formulas

INTRODUCTION TO UNIT 1—ELECTRICIAN'S MATH AND BASIC ELECTRICAL FORMULAS

In order to construct a building that will last into the future, a strong foundation is a prerequisite. The foundation is a part of the building that isn't visible in the finished structure, but is essential in erecting a building that will have the necessary strength to endure.

The math and basic electrical concepts of this unit are very similar to the foundation of a building. The concepts in this unit are the essential basics that you must understand, because you'll build upon them as you study electrical circuits and systems. As your studies continue, you'll find that a good foundation in electrical theory and math will help you understand why the *NEC* contains certain provisions.

This unit includes math and electrical fundamentals. You'll be amazed at how often your electrical studies return to the basics of this unit. Ohm's law and the electrical formulas related to it are the foundation of all electrical circuits.

Every student begins at a different level of understanding, and you may find this unit an easy review, or you may find it requires a high level of concentration. In any case, be certain that you fully understand the concepts of this unit and are able to successfully complete the questions at the end of the unit before going on. A solid foundation will help in your successful study of the rest of this textbook.

PART A—ELECTRICIAN'S MATH

Introduction

Numbers can take different forms:

Whole numbers: 1, 20, 300, 4,000, 5,000
Decimals: 0.80, 1.25, 0.75, 1.15
Fractions: ½, ¼, ⅝, ⁴⁄₃
Percentages: 80%, 125%, 250%, 500%

You'll need to be able to convert these numbers from one form to another and back again, because all of these number forms are part of electrical work and electrical calculations.

You'll also need to be able to do some basic algebra. Many people have a fear of algebra, but as you work through the material here you'll see there's nothing to fear.

1.1 Whole Numbers

Whole numbers are exactly what the term implies. These numbers don't contain any fractions, decimals, or percentages. Another name for whole numbers is "integers."

1.2 Decimals

The decimal method is used to display numbers other than whole numbers, fractions, or percentages such as, 0.80, 1.25, 1.732, and so on.

1.3 Fractions

A fraction represents part of a whole number. If you use a calculator for adding, subtracting, multiplying, or dividing, you need to convert the fraction to a decimal or whole number. To change a fraction to a decimal or whole number, divide the numerator (the top number) by the denominator (the bottom number).

► **Examples**

⅙ = one divided by six = 0.166
⅖ = two divided by five = 0.40
³⁄₆ = three divided by six = 0.50
⁵⁄₄ = five divided by four = 1.25
⁷⁄₂ = seven divided by two = 3.50

1.4 Percentages

A percentage is another method used to display a value. One hundred percent (100%) means all of a value; fifty percent (50%) means one-half of a value, and twenty-five percent (25%) means one-fourth of a value.

For convenience in multiplying or dividing by a percentage, convert the percentage value to a whole number or decimal, and then use the result for the calculation. When changing a percent value to a decimal or whole number, drop the percentage symbol and move the decimal point two places to the left. Figure 1–1

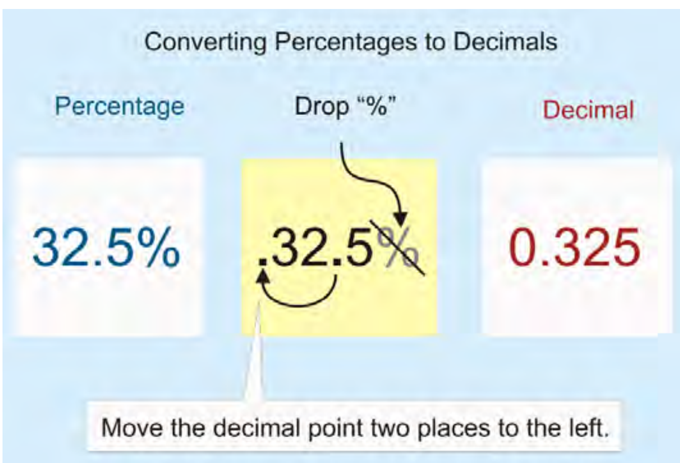

Figure 1–1

► Examples

Percentage	*Number*
32.50%	*0.325*
80%	*0.80*
125%	*1.25*
250%	*2.50*

1.5 Multiplier

When a number needs to be changed by multiplying it by a percentage, the percentage is called a multiplier. The first step is to convert the percentage to a decimal, then multiply the original number by the decimal value.

► Example 1

Question: *An overcurrent device (circuit breaker or fuse) must be sized no less than 125 percent of the continuous load. If the load is 80A, the overcurrent device will have to be sized no smaller than _____.* Figure 1–2

(a) 75A (b) 80A (c) 100A (d) 125A

Answer: *(c) 100A*

Step 1: Convert 125 percent to a decimal: 1.25

Step 2: Multiply the value of the 80A load by 1.25 = 100A

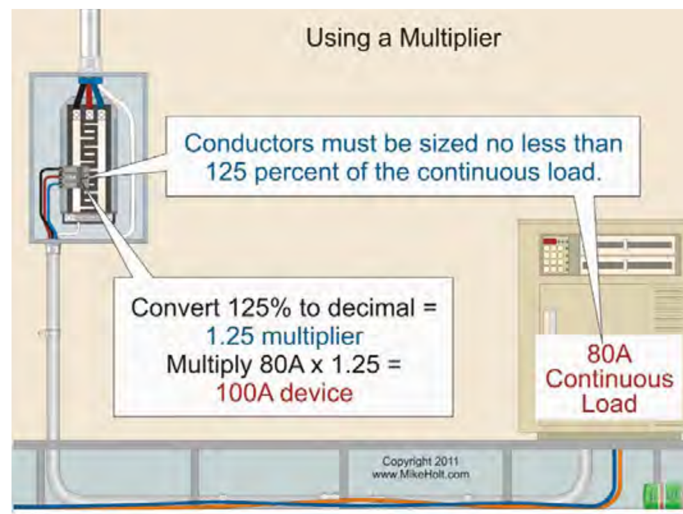

Figure 1–2

► Example 2

Question: *The maximum continuous load on an overcurrent device is limited to 80 percent of the device rating. If the overcurrent device is rated 50A, what's the maximum continuous load permitted on the overcurrent device?* Figure 1–3

(a) 40A (b) 50A (c) 75A (d) 100A

Answer: *(a) 40A*

Step 1: Convert 80 percent to a decimal: 0.80

Step 2: Multiply the value of the 50A device rating by 0.80 = 40A

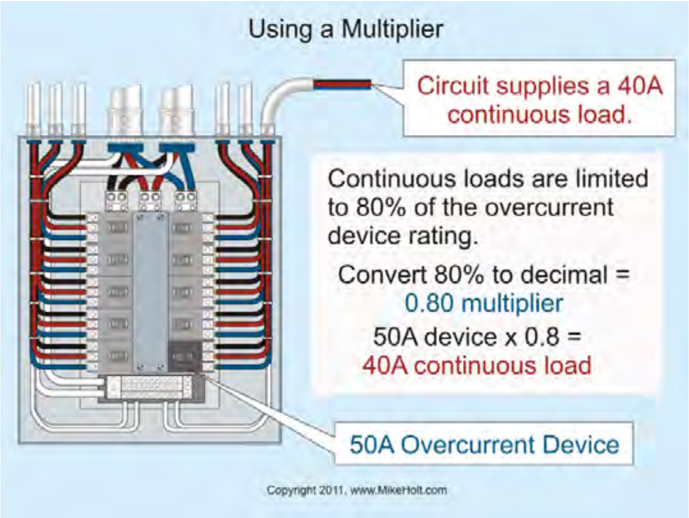

Figure 1–3

1.6 Percent Increase

Use the following steps to increase a number by a specific percentage:

Step 1: Convert the percent to a decimal value.

Step 2: Add one to the decimal value to create the multiplier.

Step 3: Multiply the original number by the multiplier found in Step 2.

► Example 1

Question: *How do you increase the whole number 45 by 35 percent?*

Step 1: Convert 35 percent to decimal form: 0.35

Step 2: Add one to the decimal value: 1 + 0.35 = 1.35

Step 3: Multiply 45 by the multiplier 1.35: 45 x 1.35 = 60.75

► Example 2

Question: *If the feeder demand load for a range is 8 kW and it's required to be increased by 15 percent, the total calculated load will be _____.* Figure 1–4

(a) 6.80 kW (b) 8 kW (c) 9.20 kW (d) 15 kW

Answer: *(c) 9.20 kW*

Step 1: Convert the percentage increase required to decimal form: 15 percent = 0.15

Step 2: Add one to the decimal: 1 + 0.15 = 1.15

Step 3: Multiply 8 by the multiplier 1.15: 8 kW x 1.15 = 9.20 kW

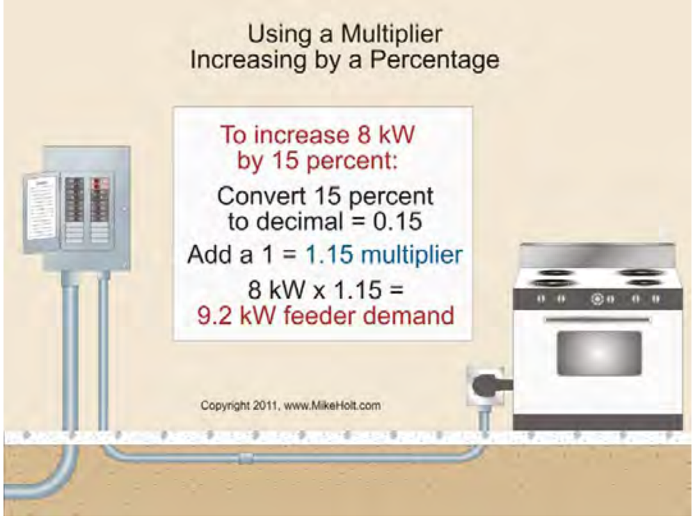

Figure 1–4

1.7 Reciprocals

To obtain the reciprocal of a number, convert the number into a fraction with the number one as the numerator (the top number). It's also possible to calculate the reciprocal of a decimal number. Determine the reciprocal of a decimal number by following these steps:

Step 1: Convert the number to a decimal value.

Step 2: Divide the value into the number one.

► Example 1

Question: *What's the reciprocal of 80 percent?*

(a) 0.80 (b) 100% (c) 125% (d) 150%

Answer: *(c) 125%*

Step 1: Convert 80 percent into a decimal (move the decimal two places to the left): 80 percent = 0.80

Step 2: Divide 0.80 into the number one: 1/0.80 = 1.25 or 125 percent

► Example 2

Question: *What's the reciprocal of 125 percent?*

(a) 75% (b) 0.80 (c) 100% (d) 125%

Answer: *(b) 0.80*

Step 1: Convert 125 percent into a decimal: 125 percent = 1.25

Step 2: Divide 1.25 into the number one: 1/1.25 = 0.80 or 80 percent

1.8 Squaring a Number

Squaring a number means multiplying the number by itself.

$10^2 = 10 \times 10 = 100$ or $23^2 = 23 \times 23 = 529$

► Example 1

Question: *What's the power consumed in watts by a 12 AWG conductor that's 200 ft long, and has a total resistance of 0.40 ohms, if the current (I) in the circuit conductors is 16A? (Answers are rounded to the nearest 50).*

Formula: Power = I^2 x R

(a) 50W (b) 100W (c) 150W (d) 200W

Answer: *(b) 100W*

P = I^2 x R

I = 16A

R = 0.40 ohms

P = $16A^2$ x 0.40 ohms

P = 16A x 16A x 0.40 ohms

P = 102.40W

► Example 2

Question: *What's the area in square inches (sq in.) of a trade size 1 raceway with an inside diameter of 1.049 in.?*

Formula: Area = π x r^2

π = 3.14

r = radius (equal to 0.50 of the diameter)

(a) 0.34 sq in. (b) 0.50 sq in. (c) 0.86 sq in. (d) 1 sq in.

Answer: *(c) 0.86 sq in.*

Area = π x r^2

Area = 3.14 x $(0.50 \times 1.049)^2$

Area = 3.14 x 0.5245^2

Area = 3.14 x (0.5245 x 0.5245)

Area = 3.14 x 0.2751

Area = 0.86 sq in.

► Example 3

Question: *What's the sq in. area of an 8 in. pizza?* **Figure 1–5A**

(a) 25 sq in. (b) 50 sq in. (c) 64 sq in. (d) 75 sq in.

Answer: *(b) 50 sq in.*

Area = π x r^2

Area = 3.14 x $(0.50 \times 8)^2$

Area = 3.14 x 4^2

Area = 3.14 x (4 x 4)

Area = 3.14 x 16

Area = 50 sq in.

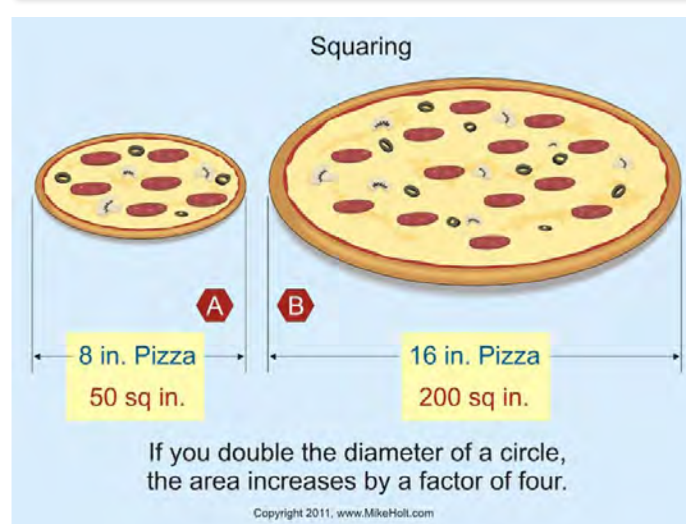

Figure 1–5

► Example 4

Question: *What's the sq in. area of a 16 in. pizza?* Figure 1–5B

(a) 100 sq in. (b) 150 sq in. (c) 200 sq in. (d) 256 sq in.

Answer: *(c) 200 sq in.*

Area = π x r²

Area = 3.14 x (0.50 x 16)²
Area = 3.14 x 8²
Area = 3.14 x (8 x 8)
Area = 3.14 x 64
Area = 200 sq in.

Author's Comment: As you see in Examples 3 and 4, if you double the diameter of the circle, the area contained in the circle is increased by a factor of four! By the way, a large pizza is always cheaper per sq in. than a small pizza.

1.9 Parentheses

Whenever numbers are in parentheses, complete the mathematical function within the parentheses before proceeding with the rest of the problem.

Parentheses are used to group steps of a process in the correct order. For instance, adding the sum of 3 and 15 to the product of 4 and 2 equals 26.

(3 + 15) + (4 x 2) = 18 + 8 = 26

► Example

Question: *What's the current of a 36,000W, 208V, three-phase load?* Figure 1–6

Ampere (I) = Watts/(E x 1.732)

(a) 50A (b) 100A (c) 150A (d) 360A

Answer: *(b) 100A*

Step 1: Perform the operation inside the parentheses first—determine the product of: 208V x 1.732 = 360V

Step 2: Divide 36,000W by 360V = 100A

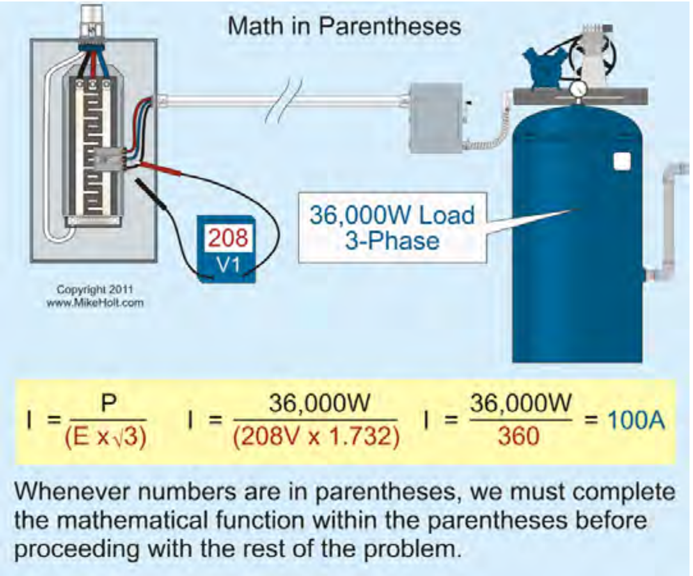

Figure 1–6

1.10 Square Root

Deriving the square root of a number ($\sqrt{n}$) is the opposite of squaring a number. The square root of 36 is a number that, when multiplied by itself, gives the product 36. The $\sqrt{36}$ equals six, because six, multiplied by itself (which can be written as 6^2) equals the number 36.

Because it's difficult to do this manually, just use the square root key of your calculator.

$\sqrt{3}$: Following your calculator's instructions, enter the number 3, then press the square root key = 1.732.

$\sqrt{1{,}000}$: enter the number 1,000, then press the square root key = 31.62.

If your calculator doesn't have a square root key, don't worry about it. For all practical purposes in using this textbook, the only number you need to know the square root of is 3. The square root of 3 equals approximately 1.732.

To add, subtract, multiply, or divide a number by a square root value, determine the decimal value and then perform the math function.

▶ Example 1

Question: *What's 36,000W/(208V x $\sqrt{3}$) equal to?*

(a) 100A (b) 120A (c) 208A (d) 360A

Answer: *(a) 100A*

Step 1: Determine the decimal value for the $\sqrt{3} = 1.732$

Step 2: Divide 36,000W by (208V x 1.732) = 100A

▶ Example 2

Question: *The phase voltage of a 120/208V system is equal to 208V/$\sqrt{3}$, which is ______.*

(a) 120V (b) 208V (c) 360V (d)480V

Answer: *(a) 120V*

Step 1: Determine the decimal value for the $\sqrt{3} = 1.732$

Step 2: Divide 208V by 1.732 = 120V

1.11 Volume

The volume of an enclosure is expressed in cubic inches (cu in.). It's determined by multiplying the length, by the width, by the depth of the enclosure.

▶ Example

Question: *What's the volume of a box that has the dimensions of 4 x 4 x 1½ in.?* **Figure 1–7**

(a) 12 cu in. (b) 20 cu in. (c) 24 cu in. (d) 30 cu in.

Answer: *(c) 24 cu in.*

1½ = 1.50
4 x 4 x 1.50 = 24 cu in.

Author's Comment: The actual volume of a 4 in. square electrical box is less than 24 cu in. because the interior dimensions may be less than the nominal size and often corners are rounded, so the allowable volume is given in the *NEC* Table 314.16(A).

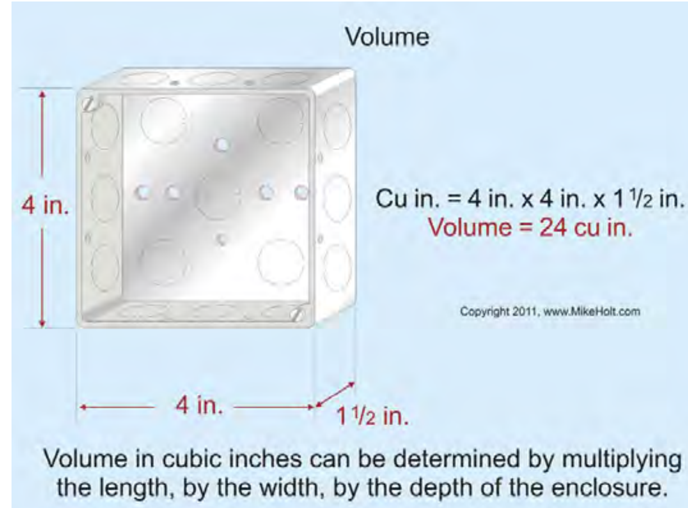

Figure 1–7

1.12 Kilo

The letter "k" is used in the electrical trade to abbreviate the metric prefix "kilo," which represents a value of 1,000.

To convert a number which includes the "k" prefix to units, multiply the number preceding the "k" by 1,000.

▶ Example 1

Question: *What's the wattage value for an 8 kW rated range?*

(a) 8W (b) 800W (c) 4,000W (d) 8,000W

Answer: *(d) 8,000W*

To convert a unit value to a "k" value, divide the number by 1,000 and add the "k" suffix.

▶ Example 2

Question: *What's the kW rating of a 300W load?* **Figure 1–8**

(a) 0.30 kW (b) 30 kW (c) 300 kW (d) 3,000 kW

Answer: *(a) 0.30 kW*

kW = Watts/1,000
kW = 300W/1,000 = 0.30 kW

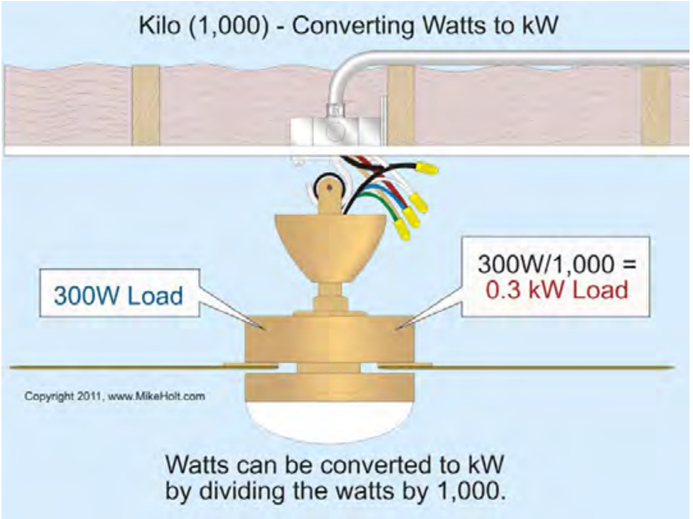

Figure 1–8

Author's Comment: The use of the letter "k" isn't limited to "kW." It's also used for kVA (1,000 volt-amperes), kcmil (1,000 circular mils) and other units such as kft (1,000 feet).

1.13 Rounding Off

There's no specific rule for rounding off, but rounding to two or three "significant digits" should be sufficient for most electrical calculations. Numbers below five are rounded down, while numbers five and above are rounded up.

0.1245—fourth number is five or above =
0.125 rounded up

1.674—fourth number is below five =
1.67 rounded down

21.99—fourth number is five or above =
22 rounded up

367.20—fourth number is below five =
367 rounded down

Rounding Answers for Multiple Choice Questions

You should round your answers in the same manner as the multiple choice selections given in the question.

► Example

Question: *The sum* of 12, 17, 28, and 40 is equal to ______.*

(a) 70 (b) 80 (c) 90 (d) 100

Answer: *(d) 100*

**A sum is the result of adding numbers.*

The sum of these values equals 97, but that answer isn't listed as one of the choices. The multiple choice selections in this case are rounded off to the closest "tens."

1.14 Testing Your Answer for Reasonableness

When working with any mathematical calculation, don't just blindly do the calculation and assume it's correct. When you perform a mathematical calculation, you need to know if the answer is greater than or less than the values given in the problem. Always do a "reality check" to be certain that your answer isn't nonsense. Even the best of us make mistakes at times, so always examine your answer to make sure it makes sense!

► Example

Question: *The input of a transformer is 300W; the transformer efficiency is 90 percent. What's the transformer output?* Figure 1–9

(a) 270W (b) 300W (c) 333W (d) 500W

Answer: *(a) 270W*

Since the output has to be less than the input (300W), you won't have to perform any mathematical calculation; the only multiple choice selection that's less than 300W is (a) 270W.

The math to work out the answer is:
300W x 0.90 = 270W

To check your multiplication, use division:
270W/0.90 = 300W

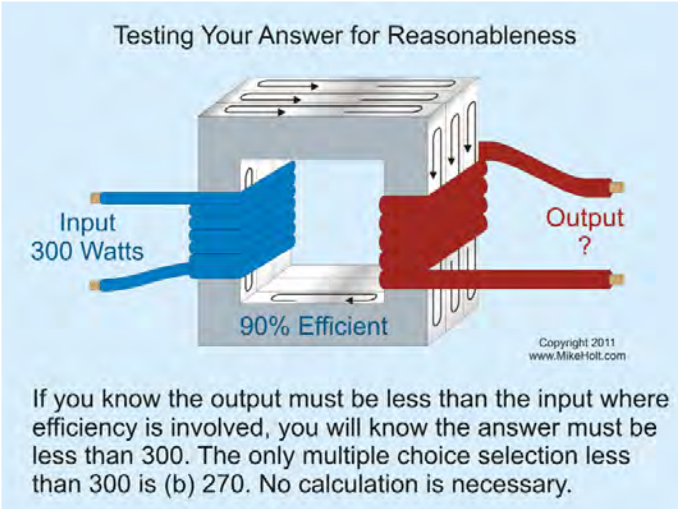

Figure 1–9

> **Author's Comment:** One of the nice things about mathematical equations is that you can usually test to see if your answer is correct. To do this test, substitute the answer you arrived at back into the equation you're working with, and verify that it indeed equals out correctly. This method of checking your math will become easier once you know more of the formulas and how they relate to each other.

PART B—BASIC ELECTRICAL FORMULAS

Introduction

Now that you've mastered the math and understand some basics about electrical circuits, you're ready to take your knowledge of electrical formulas to the next level. One of the things we're going to do here is strengthen your proficiency with Ohm's Law.

Many false notions about the application of Article 250—Grounding and Bonding and Chapter 3—Wiring Methods (both in the *NEC*) arise when people use Ohm's Law only to solve practice problems on paper but lack a real understanding of how that law works and how to apply it. After completing this unit, you'll have that understanding, and won't be subject to those false notions—or the unsafe conditions they lead to.

But we won't stop with Ohm's Law. You're also going to have a high level of proficiency with the power equation. One of the tools for handling the power equation with ease—and Ohm's Law—is the power wheel. You'll be able to use it to solve all kinds of problems.

1.15 Electrical Circuit

A basic electrical circuit consists of the power source, the conductors, and the load. A switch can be placed in series with the circuit conductors to control the operation of the load (turning it on or off). Figure 1–10

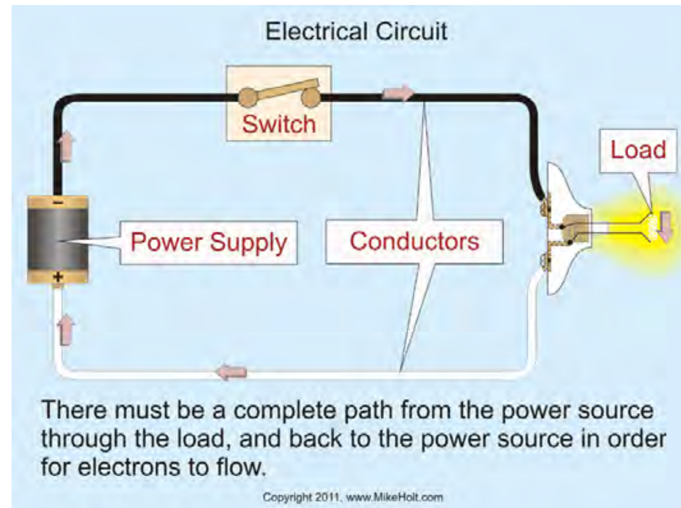

Figure 1–10

> **Author's Comment:** According to the "electron current flow theory," current always flows from the negative terminal of the source, through the circuit and load, to the positive terminal of the source.

1.16 Power Source

The power necessary to move electrons out of their orbit around the nucleus of an atom can be produced by chemical, magnetic, photovoltaic, and other means. The two categories of power sources are direct current (dc) and alternating current (ac).

Direct Current

The polarity and the output voltage from a direct-current power source never change direction. One terminal is negative and the other is positive, relative to each other. Direct-current power is often produced by batteries, direct-current generators, and electronic power supplies. Figure 1–11

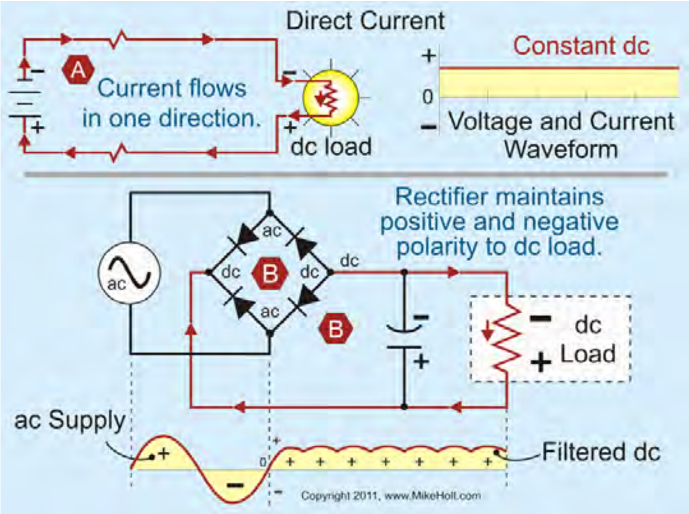

Figure 1–11

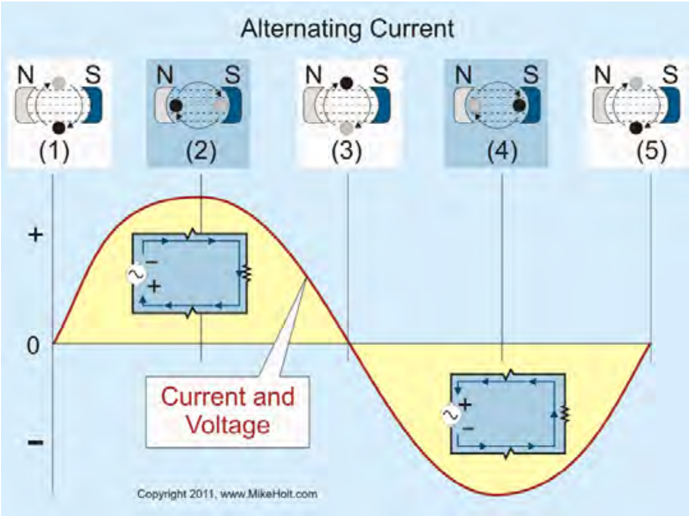

Figure 1–12

Direct current is used for electroplating, street trolley and railway systems, or where a smooth and wide range of speed control is required for a motor-driven application. Direct current is also used for control circuits and electronic instruments.

Alternating Current

Alternating-current power sources produce a voltage that changes polarity and magnitude. Alternating current is produced by an alternating-current power source such as an alternating-current generator. The major advantage of alternating current over direct current is that voltage can be changed through the use of a transformer. Figure 1–12

> **Author's Comment:** Alternating current accounts for more than 90 percent of all electric power used throughout the world.

1.17 Conductance

Conductance, or conductivity, is the property of a metal that permits current to flow. The best conductors in order of their conductivity are silver, copper, gold, and aluminum. Copper is most often used for electrical applications. Figure 1–13

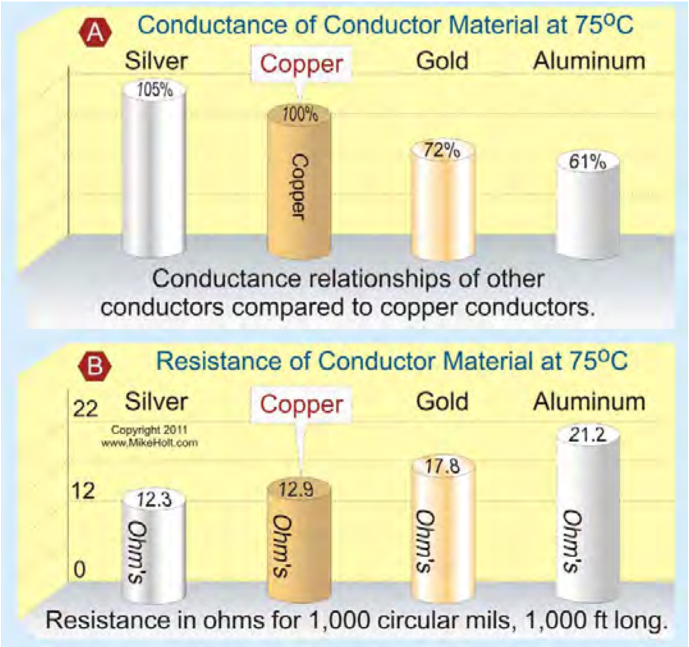

Figure 1–13

1.18 Circuit Resistance

The total resistance of a circuit includes the resistance of the power supply, the circuit wiring, and the load. Appliances such as heaters and toasters use high-resistance conductors to produce the heat needed for the application. Because the resistances of the power source and conductor are so much smaller than that of the load, they're generally ignored in circuit calculations. Figure 1–14

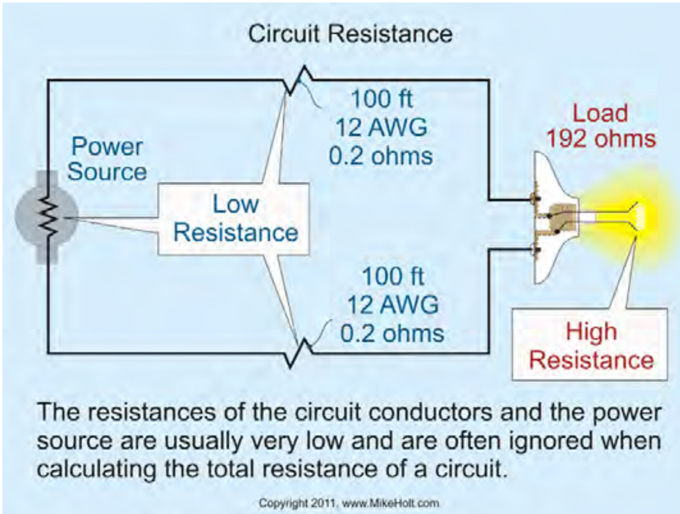

Figure 1–14

1.19 Ohm's Law

Ohm's Law expresses the relationship between a direct-current circuit's current intensity (I), electromotive force (E), and its resistance (R). This is expressed by the formula: I = E/R.

> **Author's Comment:** The German physicist Georg Simon Ohm (1787-1854) stated that current is directly proportional to voltage, and inversely proportional to resistance. Figure 1–15

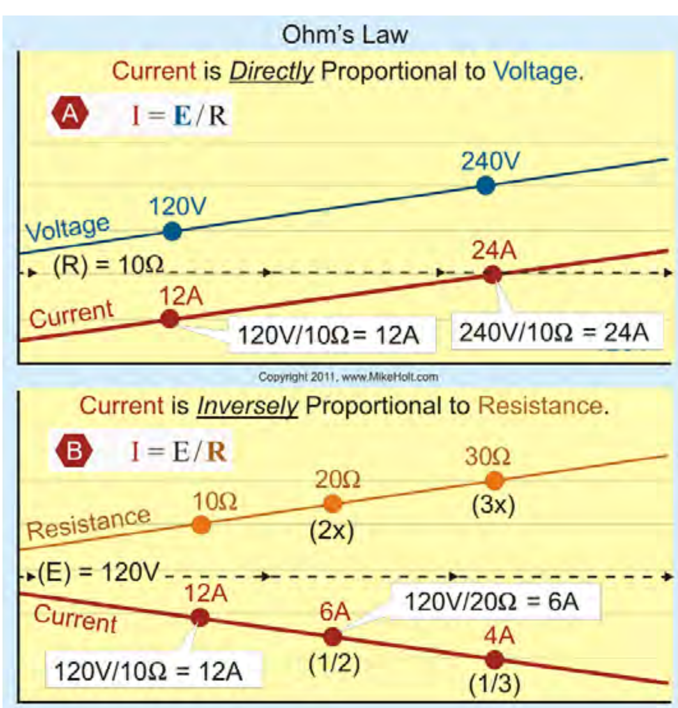

Figure 1–15

Direct proportion means that changing one factor results in a direct change to another factor in the same direction and by the same magnitude. Figure 1–15A

If the voltage increases 25 percent, the current increases 25 percent—in direct proportion (for a given resistance). If the voltage decreases 25 percent, the current decreases 25 percent—in direct proportion (for a given resistance).

Inverse proportion means that increasing one factor results in a decrease in another factor by the same magnitude, or a decrease in one factor will result in an increase of the same magnitude in another factor. Figure 1–15B

If the resistance increases by 25 percent, the current decreases by 25 percent—in inverse proportion (for a given voltage), or if the resistance decreases by 25 percent, the current increases by 25 percent—in inverse proportion (for a given voltage).

1.20 Ohm's Law and Alternating Current

Direct Current

In a direct-current circuit, the only opposition to current flow is the physical resistance of the material through which the current flows. This opposition is called resistance and is measured in ohms.

Alternating Current

In an alternating-current circuit, there are three factors that oppose current flow: the resistance of the material; the inductive reactance of the circuit; and the capacitive reactance of the circuit.

> **Author's Comment:** For now, we'll assume that the effects of inductance and capacitance on the circuit are insignificant and they'll be ignored.

1.21 Ohm's Law Formula Circle

Ohm's Law, the relationship between current, voltage, and resistance expressed in the formula, E = I x R, can be transposed to I = E/R or R = E/I. In order to use these formulas, two of the values must be known.

> **Author's Comment:** Place your thumb on the unknown value in Figure 1–16, and the two remaining variables will "show" you the correct formula.

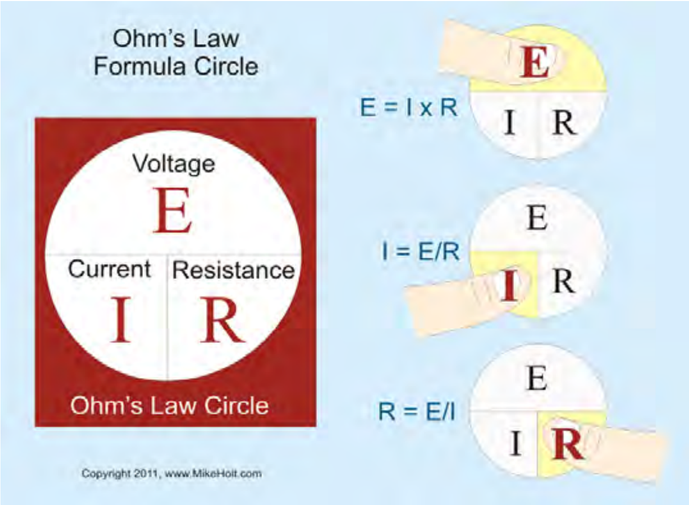

Figure 1–16

► Current Example

Question: *120V supplies a lamp that has a resistance of 192 ohms. What's the current flow in the circuit?* **Figure 1–17**

(a) 0.50A *(b) 0.60A* *(c) 1.30A* *(d) 2.50A*

Answer: *(b) 0.60A*

Step 1: What's the question? What's "I?"

Step 2: What do you know? E = 120V, R = 192 ohms

Step 3: The formula is ***I = E/R***

Step 4: The answer is I = 120V/192 ohms

Step 5: The answer is I = 0.625A

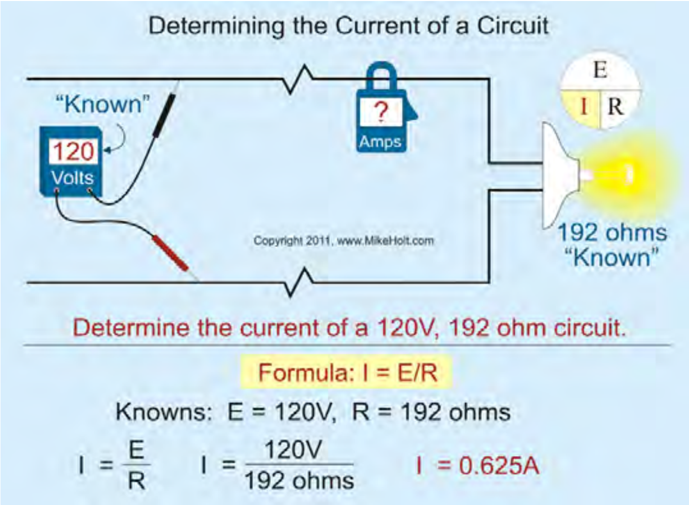

Figure 1–17

► Voltage-Drop Example

Question: *What's the voltage drop over two 12 AWG conductors (resistance of 0.20 ohms per 100 ft) supplying a 16A load located 50 ft from the power supply?* **Figure 1–18**

(a) 1.60V *(b) 3.20V* *(c) 16V* *(d) 32V*

Answer: *(b) 3.20V*

Step 1: What's the question? What's "E?"

Step 2: What do you know about the conductors?

I = 16A, R = 0.20 ohms. The NEC lists the alternating-current resistance of 1,000 ft of 12 AWG as 2 ohms [Chapter 9, Table 8]. The resistance of 100 ft is equal to 0.20 ohms. **Figure 1–19**

Step 3: The formula is ***E = I x R****.*

Step 4: The answer is E = 16A x 0.20 ohms

Step 5: The answer is E = 3.20V

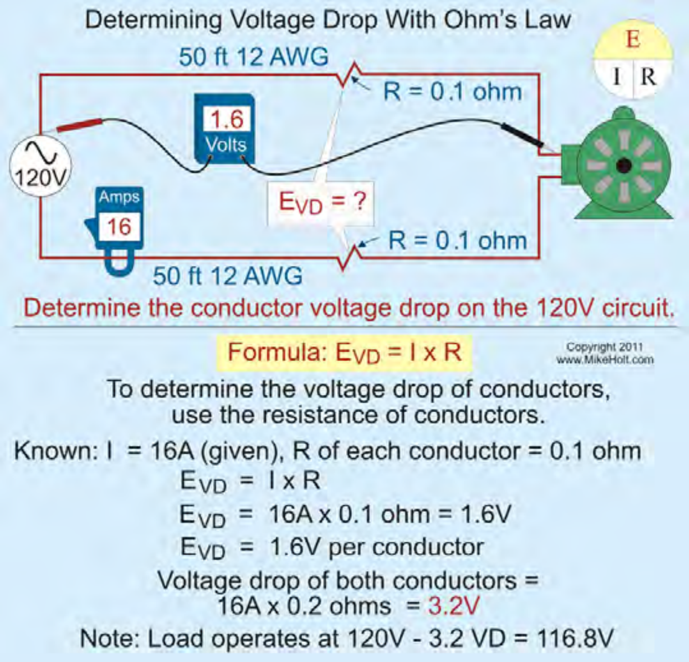

Figure 1–18

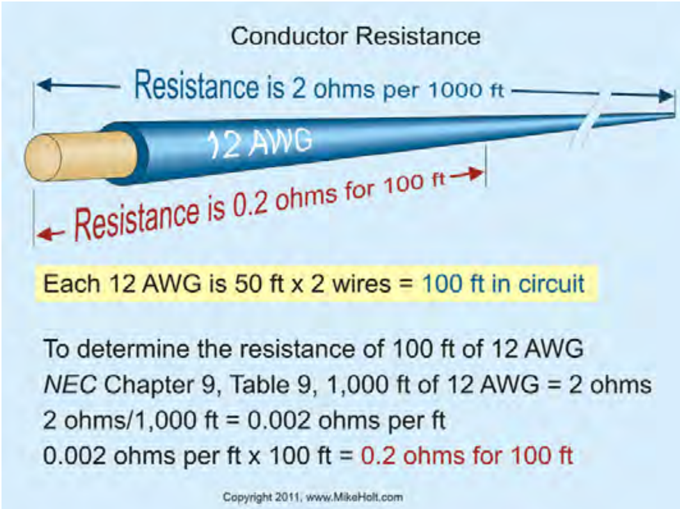

Figure 1–19

▶ Resistance Example

Question: *What's the resistance of the circuit conductors when the conductor voltage drop is 3V and the current flowing in the circuit is 100A?* Figure 1–20

(a) 0.03 ohms (b) 2 ohms (c) 30 ohms (d) 300 ohms

Answer: *(a) 0.03 ohms*

Step 1: What's the question? What's "R?"

Step 2: What do you know about the conductors?
E = 3V dropped, I = 100A

Step 3: The formula is ***R = E/I***

Step 4: The answer is R = 3V/100A

Step 5: The answer is R = 0.03 ohms

1.22 PIE Formula Circle

The PIE formula circle demonstrates the relationship between power, current, and voltage, and is expressed in the formula **P = I x E**. This formula can be transposed to **I = P/E** or **E = P/I**. In order to use these formulas, two of the values must be known.

> **Author's Comment:** Place your thumb on the unknown value in Figure 1–21 and the two remaining variables will "show" you the correct formula.

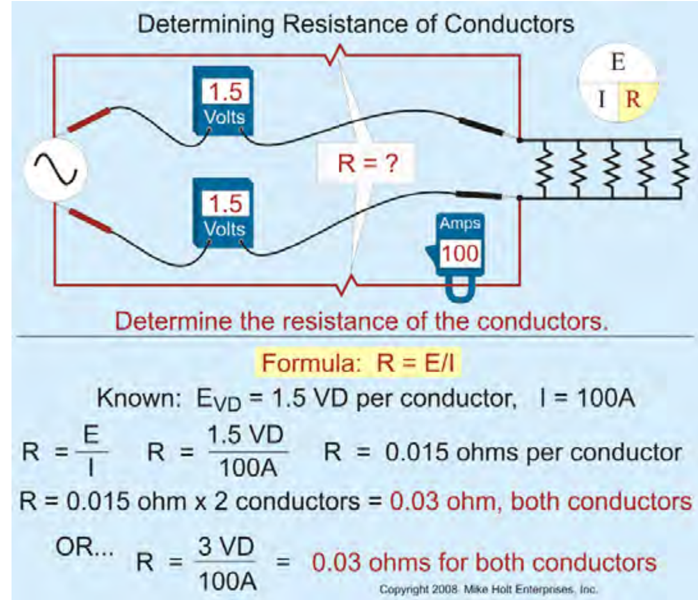

Figure 1–20

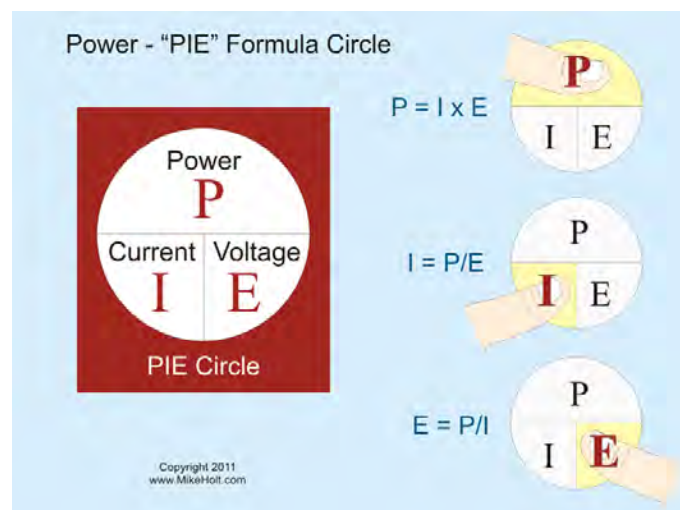

Figure 1–21

► Power Loss Example

Question: *What's the power loss in watts for two conductors that carry 12A and have a voltage drop of 3.60V?* **Figure 1–22**

(a) 4.30W (b) 24W (c) 43.20W (d) 432W

Answer: *(c) 43.20W*

Step 1: What's the question? What's "P?"

Step 2: What do you know? I = 12A, E = 3.60V.

Step 3: The formula is ***P = I x E****.*

Step 4: The answer is P = 12A x 3.60V.

Step 5: The answer is 43.20W.

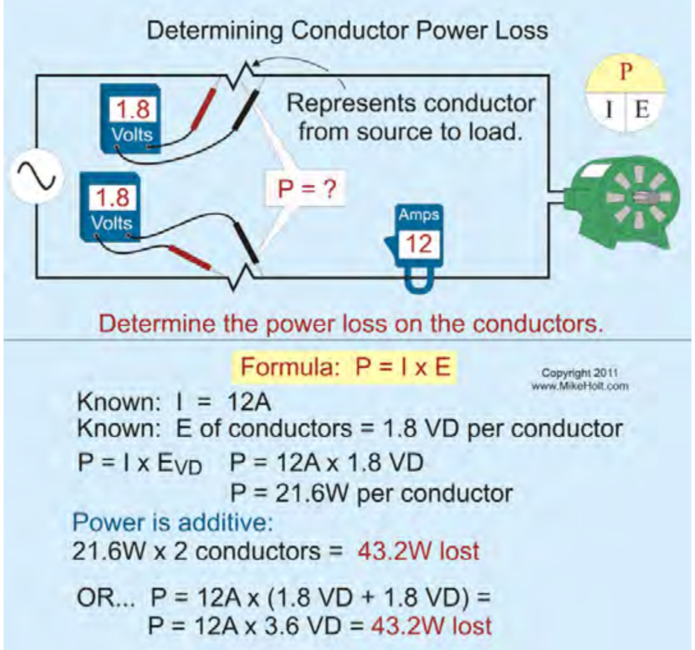

Figure 1–22

► Current Example

Question: *What's the current flow in amperes through a 7.50 kW heat strip rated 230V when connected to a 230V power supply?* **Figure 1–23**

(a) 25A (b) 33A (c) 39A (d) 230A

Answer: *(b) 33A*

Step 1: What's the question? What's "I?"

Step 2: What do you know? P = 7,500W, E = 230V.

Step 3: The formula is ***I = P/E****.*

Step 4: The answer is I = 7,500W/230V.

Step 5: The answer is 32.60A.

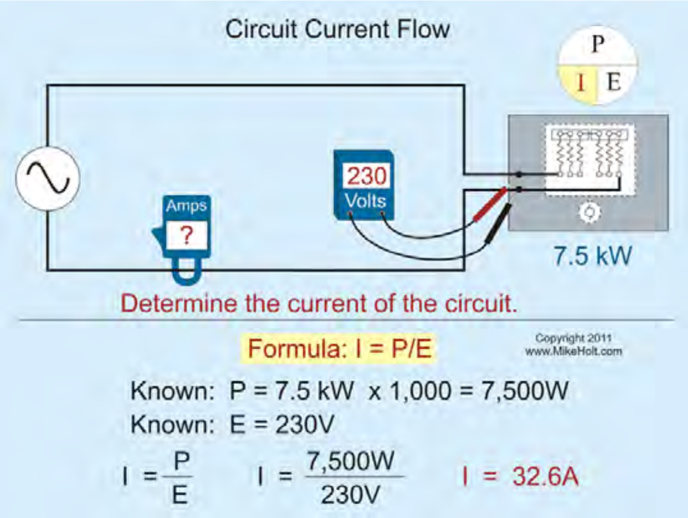

Figure 1–23

1.23 Formula Wheel

The formula wheel is a combination of the Ohm's Law and the PIE formula wheels. The formulas in the formula wheel can be used for direct-current circuits or alternating-current circuits with unity power factor. **Figure 1–24**

> **Author's Comment:** Unity power factor is explained in Unit 3. For the purpose of this unit, we'll assume a power factor of 1.0 for all alternating-current circuits.

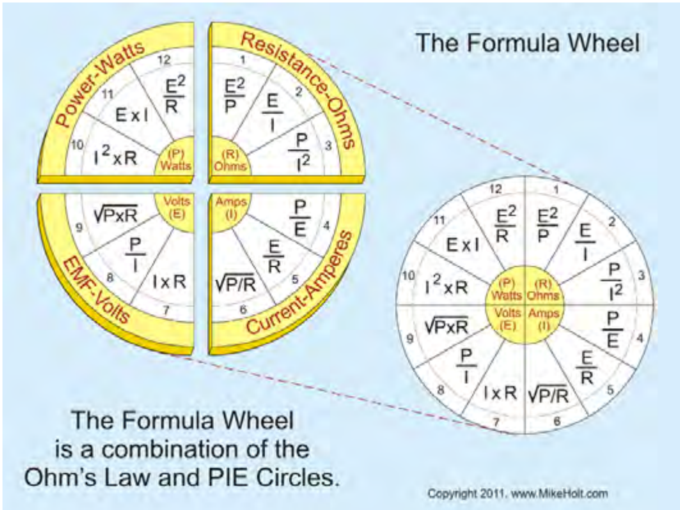

Figure 1–24

1.24 Using the Formula Wheel

The formula wheel is divided into four sections with three formulas in each section. Figure 1–25. When working the formula wheel, the key to calculating the correct answer is to follow these steps:

Step 1: Know what the question is asking for: I, E, R, or P.

Step 2: Determine the knowns: I, E, R, or P.

Step 3: Determine which section of the formula wheel applies: I, E, R, or P and select the formula from that section based on what you know.

Step 4: Work out the calculation.

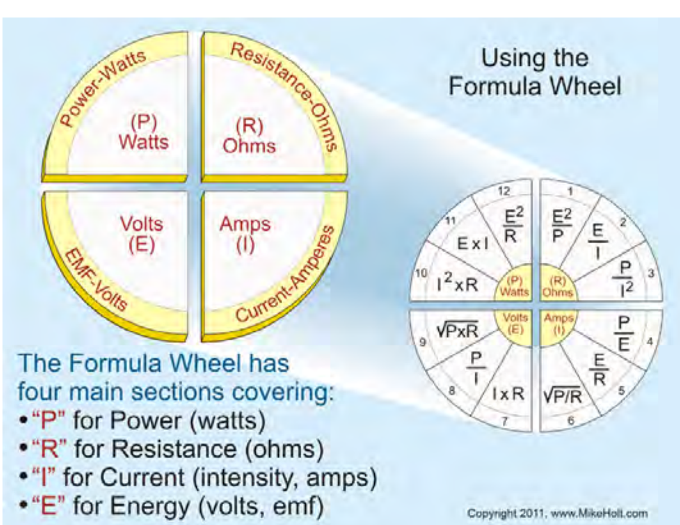

Figure 1–25

► Example

Question: *The total resistance of two 12 AWG conductors, 75 ft long is 0.30 ohms, and the current through the circuit is 16A. What's the power loss of the conductors?* Figure 1–26

(a) 20W (b) 75W (c) 150W (d) 300W

Answer: *(b) 75W*

Step 1: What's the question? What's the power loss of the conductors "P?"

Step 2: What do you know about the conductors?
I = 16A, R = 0.30 ohms

Step 3: What's the formula? ***P = I² x R***

Step 4: Calculate the answer: P = 16A² x 0.30 ohms = 76.80W.
The answer is 76.80W.

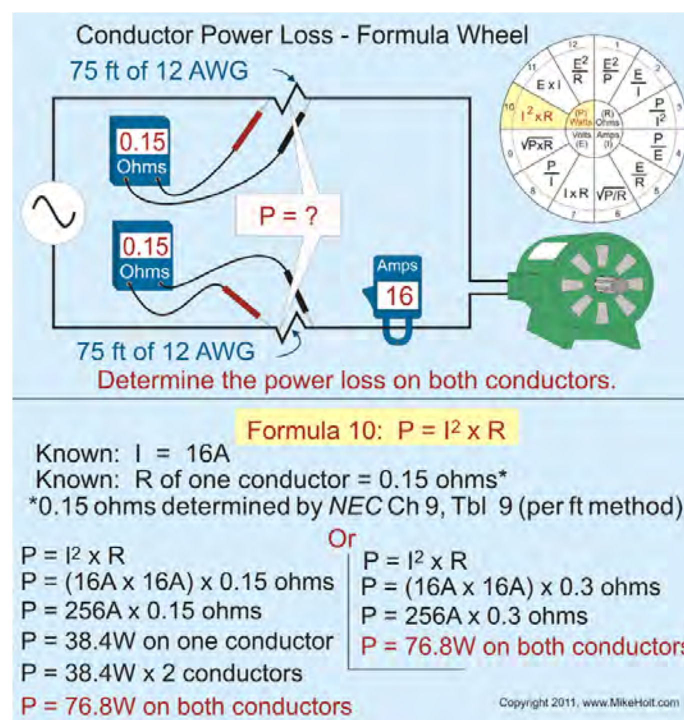

Figure 1–26

1.25 Power Losses of Conductors

Power in a circuit can be either "useful" or "wasted." Most of the power used by loads such as fluorescent lighting, motors, or stove elements is consumed in useful work. However, the heating of conductors, transformers, and motor windings is wasted work. Wasted work is still energy used; therefore it must be paid for, so we call wasted work "power loss."

► **Example**

Question: *What's the conductor power loss in watts for a 10 AWG conductor that has a voltage drop of 3 percent in a 240V circuit, and carries a current flow of 24A?* **Figure 1–27**

(a) 17W (b) 173W (c) 350W (d) 450W

Answer: *(b) 173W*

Step 1: What's the problem asking you to find? What's wasted "P?"

Step 2: What do you know about the conductors?

I = 24A
E = 240V x 3%
E = 240V x 0.03
E = 7.20V

Step 3: The formula is ***P = I x E****.*

Step 4: Calculate the answer: P = 24A x 7.20V = 172.80W. The answer is 172.80W.

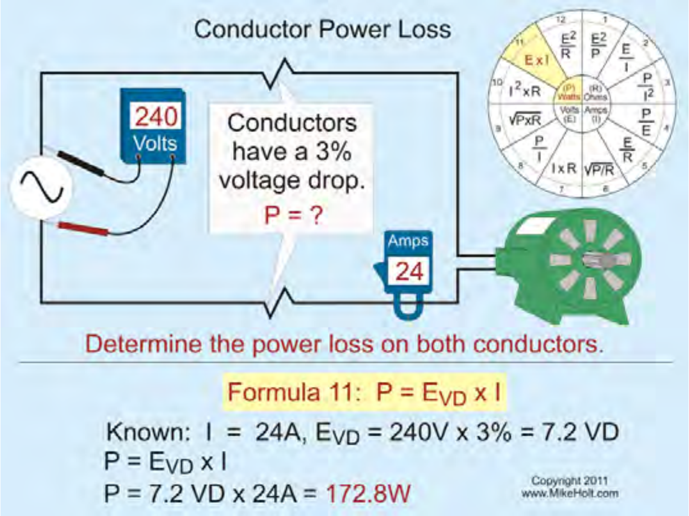

Figure 1–27

1.26 Cost of Power

Since electric bills are based on power consumed in watts, we should understand how to determine the cost of power.

► **Example**

Question: *What does it cost per year (at 8.60 cents per kWh) for the power loss of two 10 AWG circuit conductors that have a total resistance of 0.30 ohms with a current flow of 24A?* **Figure 1–28**

(a) $1.30 (b) $13 (c) $130 (d) $1,300

Answer: *(c) $130*

Step 1: Determine the amount of power consumed:

P = I2 x R
P = $24A^2$ x 0.30 ohms
P = 172.80W

Step 2: Convert the answer in Step 1 to kW:
P = 172.80W/1,000W
P = 0.1728 kW

Step 3: Determine the cost per hour:
(0.086 dollars per kWh) x 0.17280 kW = 0.01486 dollars per hr

Step 4: Determine the dollars per day:
0.01486 dollars per hr x (24 hrs per day) = 0.3567 dollars per day

Step 5: Determine the dollars per year:
0.3567 dollars per day x (365 days per year) = $130.20 per year

Author's Comment: That's a lot of money just to heat up two 10 AWG conductors for one circuit. Imagine how much it costs to heat up the conductors for an entire building!

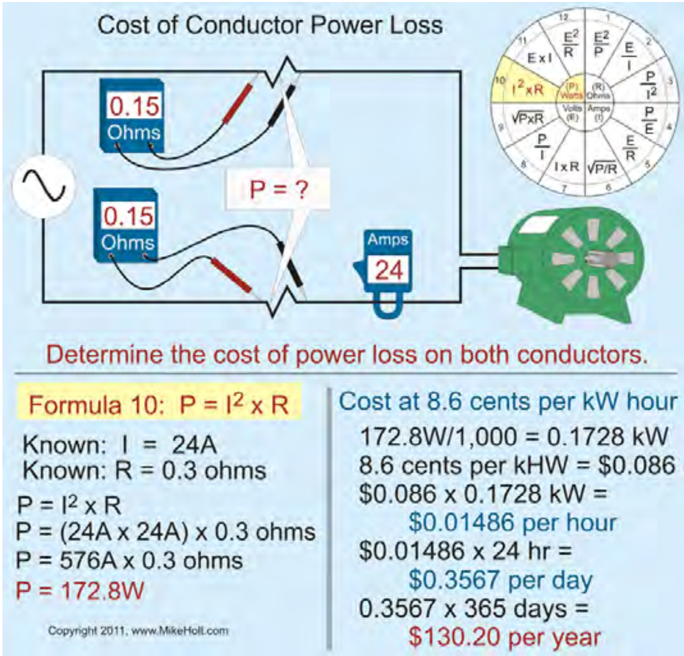

Figure 1–28

1.27 Power Changes with the Square of the Voltage

The voltage applied to a resistor dramatically affects the power consumed by that resistor. Power is determined by the square of the voltage. This means that if the voltage is doubled, the power will increase four times. If the voltage is decreased 50 percent, the power will decrease to 25 percent of its original value. Figure 1–29

► Power Example at 230V

Question: *What's the power consumed by a 9.60 kW heat strip rated 230V connected to a 230V circuit?* **Figure 1–30**

(a) 7.85 kW (b) 9.60 kW (c) 11.57 kW (d) 25 kW

Answer: *(b) 9.60 kW*

Step 1: What's the problem asking you to find?
Power consumed by the resistance.

Step 2: What do you know about the heat strip?
You were given "P = 9.60 kW" in the statement of the problem.

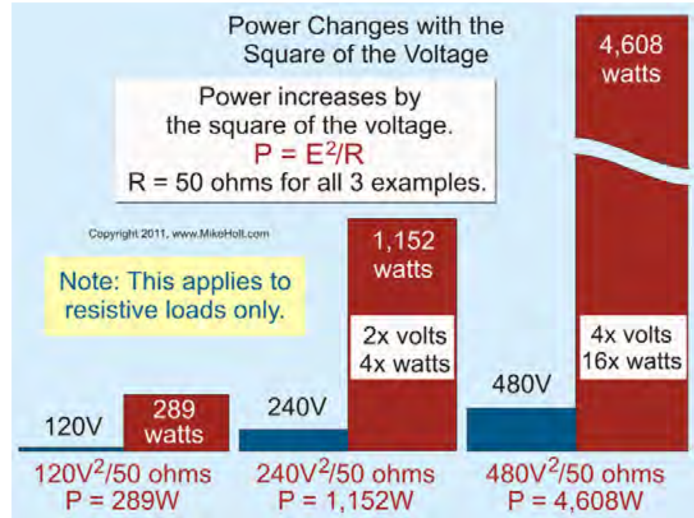

Figure 1–29

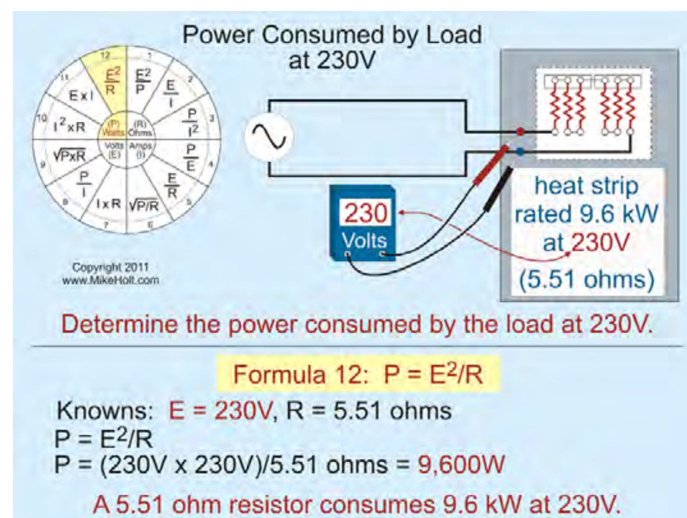

Figure 1–30

► Power Example at 208V

Question: *What's the power consumed by a 9.60 kW heat strip rated 230V connected to a 208V circuit?* **Figure 1–31**

(a) 7.85 k (b) 9.60 kW (c) 11.57 kW (d) 208 kW

Answer: *(a) 7.85 kW*

Step 1: What's the problem asking you to find?
The power consumed by the resistance.

Step 2: What do you know about the heat strip?
$E = 208V$, $R = E^2/P$
$R = 230V \times 230V/9{,}600W$
$R = 5.51$ ohms

Step 3: The formula to determine power is: $P = E2/R$.

Step 4: The answer is:
$P = 208V^2/5.51$ ohms
$P = 7{,}851W$ or 7.85 kW

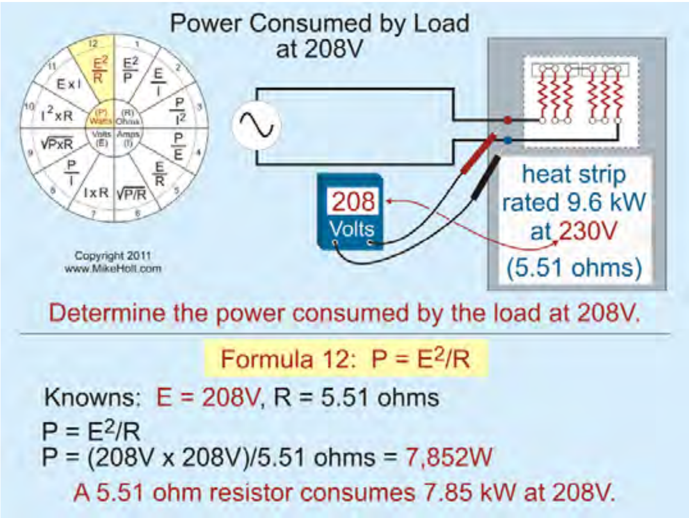

Figure 1–31

Author's Comment: It's important to realize that the resistance of the heater unit doesn't change—it's a property of the material through which the current flows and isn't dependent on the voltage applied.

Thus, for a small change in voltage, there's a considerable change in the power consumption by this heater.

Author's Comment: The current flow for this heat strip is $I = P/E$.

$P = 7{,}851W$
$E = 208V$
$I = 7{,}851W/208V$
$I = 38A$

► Power Example at 240V

Question: *What's the power consumed by a 9.60 kW heat strip rated 230V connected to a 240V circuit?* **Figure 1–32**

(a) 7.85 kW (b) 9.60 kW (c) 10.45 kW (d) 11.57 kW

Answer: *(c) 10.45 kW*

Step 1: What's the problem asking you to find?
The power consumed by the resistance.

Step 2: What do you know about the resistance?
$R = 5.51$ ohms*

**The resistance of the heat strip is determined by the formula* $R = E^2/P$.

E = Nameplate voltage rating of the resistance, 230V

P = Nameplate power rating of the resistance, 9,600W

$R = E^2/P$
$R = 230V^2/9{,}600W$
$R = 5.51$ ohms

Step 3: The formula to determine power is: $P = E^2/R$

Step 4: The answer is:
$P = 240V \times 240V/5.51$ ohms
$P = 10{,}454W$
$P = 10.45$ kW

Author's Comment: The current flow for this heat strip is $I = P/E$.

$P = 10{,}454W$
$E = 240V$
$I = 10{,}454W/240V$
$I = 44A$

As you can see, when the voltage changes, the power changes by the square of the change in the voltage, but the current changes in direct proportion to the change in the voltage.

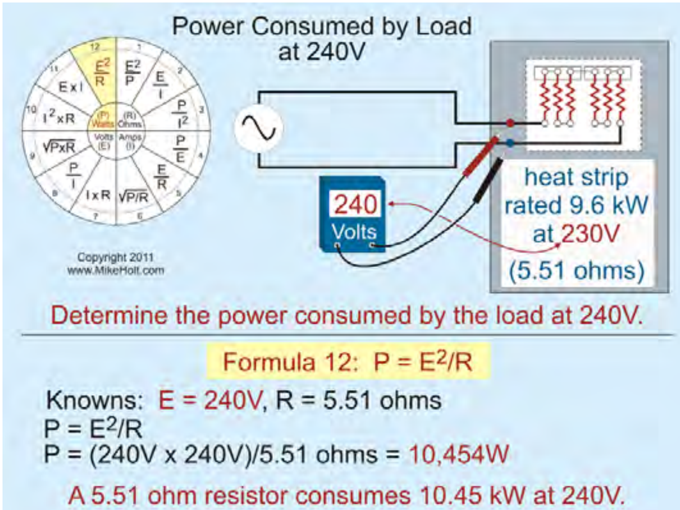

Figure 1–32

CONCLUSION TO UNIT 1—ELECTRICIAN'S MATH AND BASIC ELECTRICAL FORMULAS

You've gained skill in working with Ohm's Law and the power equation, and can use the power wheel to solve a wide variety of electrical problems. You also know how to calculate voltage drop and power loss, and can relate the costs in real dollars.

As you work through the practice questions, you'll see how well you've mastered the mathematical concepts and how ready you are to put them to use in electrical formulas. Always remember to check your answer when you're done—then you'll know you have a correct answer every time. As useful as these skills are, there's still more to learn. But, your mastery of the basic electrical formulas means you're well prepared. Work through the questions that follow, and go back over the instructional material if you have any difficulty. When you believe you know the material in Unit 1, you're ready to tackle the electrical circuits of Unit 2.

UNIT 1

Practice Questions

PRACTICE QUESTIONS FOR UNIT 1—ELECTRICIAN'S MATH AND BASIC ELECTRICAL FORMULAS

PART A—ELECTRICIAN'S MATH

1.3 Fractions

1. The decimal equivalent for the fraction "½" is _____.

   (a) 0.50
   (b) 0.70
   (c) 2
   (d) 5

2. The approximate decimal equivalent for the fraction "4⁄18" is _____.

   (a) 0.20
   (b) 2.50
   (c) 3.50
   (d) 4.50

1.4 Percentages

3. To change a percent value to a decimal or whole number, drop the percentage sign and move the decimal point two places to the _____.

   (a) right
   (b) left
   (c) depends
   (d) none of these

4. The decimal equivalent for "75 percent" is _____.

   (a) 0.075
   (b) 0.75
   (c) 7.50
   (d) 75

5. The decimal equivalent for "225 percent" is _____.

   (a) 0.225
   (b) 2.25
   (c) 22.50
   (d) 225

6. The decimal equivalent for "300 percent" is _____.

   (a) 0.03
   (b) 0.30
   (c) 3
   (d) 30.00

1.5 Multiplier

7. The method of increasing a number by another number is done by using a ______.

   (a) percentage
   (b) decimal
   (c) fraction
   (d) multiplier

8. An overcurrent device (circuit breaker or fuse) must be sized no less than 125 percent of the continuous load. If the load is 16A, the overcurrent device will have to be sized at no less than _____.

   (a) 17A
   (b) 20A
   (c) 23A
   (d) 30A

9. The maximum continuous load on an overcurrent device is limited to 80 percent of the device rating. If the overcurrent device is rated 100A, the maximum continuous load is _____.

   (a) 72A
   (b) 80A
   (c) 90A
   (d) 125A

1.6 Percent Increase

10. The feeder calculated load for an 8 kW load, increased by 20 percent is _____.

    (a) 8 kW
    (b) 9.60 kW
    (c) 10 kW
    (d) 12 kW

1.7 Reciprocals

11. What's the reciprocal of 1.25?

    (a) 0.80
    (b) 1.10
    (c) 1.25
    (d) 1.50

12. A continuous load requires an overcurrent device sized no smaller than 125 percent of the load. What's the maximum continuous load permitted on a 100A overcurrent device?

    (a) 75A
    (b) 80A
    (c) 100A
    (d) 125A

1.8 Squaring a Number

13. Squaring a number means multiplying the number by itself.

    (a) True
    (b) False

14. What's the power consumed in watts by a 12 AWG conductor that's 100 ft long and has a resistance (R) of 0.20 ohms, when the current (I) in the circuit is 16A?

    Formula: Power = I^2 x R

    (a) 50W
    (b) 75W
    (c) 100W
    (d) 200W

15. What's the approximate area in square inches of a trade size 2 raceway?

    Formula: Area = π x r^2, π = 3.14, r = radius (½ of diameter)

    (a) 1 sq in.
    (b) 2 sq in.
    (c) 3 sq in.
    (d) 4 sq in.

16. The numeric equivalent of 4^2 is _____.

    (a) 2
    (b) 8
    (c) 16
    (d) 32

17. The numeric equivalent of 12^2 is _____.

    (a) 3.46
    (b) 24
    (c) 144
    (d) 1,728

1.9 Parentheses

18. What's the maximum distance that two 14 AWG conductors can be run if they carry 16A and the maximum allowable voltage drop is 10V?

    D = (Cmil x E_{vd})/(2 x K x I)

    The cmil area of 14 AWG = 4,110 cmil [Chapter 9, Table 8]
    D = (4,110 Cmil x 10V)/(2 x 12.90 ohms x 16A)

    (a) 50 ft
    (b) 75 ft
    (c) 100 ft
    (d) 150 ft

19. What's the current in amperes of an 18 kW, 208V, three-phase load?

    Current: $I = VA/(E \times \sqrt{3})$

    Current: $I = 18{,}000W/(208V \times 1.732)$

    (a) 25A
    (b) 50A
    (c) 100A
    (d) 150A

1.10 Square Root

20. Deriving the square root of a number is almost the same as squaring a number.

    (a) True
    (b) False

21. What's the approximate square root of 1,000?

    (a) 3
    (b) 32
    (c) 100
    (d) 500

22. The square root of 3 is ______.

    (a) 1.50
    (b) 1.732
    (c) 9
    (d) 729

1.11 Volume

23. The volume of an enclosure is expressed in ______, and is calculated by multiplying the length, by the width, by the depth of the enclosure.

    (a) cubic inches
    (b) weight
    (c) inch-pounds
    (d) none of these

24. What's the volume (in cubic inches) of a 4 x 4 x 1.50 in. box?

    (a) 20 cu in.
    (b) 24 cu in.
    (c) 30 cu in.
    (d) 33 cu in.

1.12 Kilo

25. What's the kW of a 75W load?

    (a) 0.075 kW
    (b) 0.75 kW
    (c) 7.50 kW
    (d) 75 kW

1.13 Rounding Off

26. The approximate sum of 2, 7, 8, and 9 is equal to ______.

    (a) 20
    (b) 25
    (c) 30
    (d) 35

1.14 Testing Your Answer for Reasonableness

27. The output power of a transformer is 100W and the transformer efficiency is 90 percent. What's the transformer input if the output is lower than the input?

    Formula: Input = Output/Efficiency

    (a) 90W
    (b) 100W
    (c) 110W
    (d) 125W

PART B—BASIC ELECTRICAL FORMULAS

1.15 Electrical Circuit

28. An electrical circuit consists of the ______.

(a) power source
(b) conductors
(c) load
(d) all of these

29. According to the electron flow theory, electrons leave the ______ terminal of the source, flow through the conductors and load(s), and return to the ______ terminal of the source.

(a) positive, negative
(b) negative, positive
(c) negative, negative
(d) positive, positive

1.16 Power Source

30. The polarity and the output voltage from a direct-current power source changes direction. One terminal will be negative and the other will be positive at one moment, then the terminals switch polarity.

(a) True
(b) False

31. Direct current is used for electroplating, street trolley and railway systems, or where a smooth and wide range of speed control is required for a motor-driven application.

(a) True
(b) False

32. The polarity and the output voltage from an alternating-current power source never change direction.

(a) True
(b) False

33. The major advantage of alternating-current over direct-current is the ease of voltage regulation by the use of a transformer.

(a) True
(b) False

1.17 Conductance

34. Conductance is the property that permits current to flow.

(a) True
(b) False

35. The best conductors, in order of their conductivity, are gold, silver, copper, and aluminum.

(a) True
(b) False

36. Conductance, or conductivity, is the property of metal that permits current to flow. The best conductors in order of their conductivity are ______.

(a) gold, silver, copper, aluminum
(b) gold, copper, silver, aluminum
(c) silver, gold, copper, aluminum
(d) silver, copper, gold, aluminum

1.18 Circuit Resistance

37. The circuit resistance includes the resistance of the ______.

(a) power source
(b) conductors
(c) load
(d) all of these

38. Often the resistances of the power source and conductor are ignored in circuit calculations.

(a) True
(b) False

1.19 Ohm's Law

39. The Ohm's Law formula, **I = E/R**, states that current is _____ proportional to the voltage, and _____ proportional to the resistance.

    (a) indirectly, inversely
    (b) inversely, directly
    (c) inversely, indirectly
    (d) directly, inversely

40. Ohm's Law demonstrates the relationship between circuit _____.

    (a) intensity
    (b) EMF
    (c) resistance
    (d) all of these

1.20 Ohm's Law and Alternating Current

41. In a direct-current circuit, the only opposition to current flow is the physical resistance of the material. This opposition is called reactance and is measured in ohms.

    (a) True
    (b) False

42. In an alternating-current circuit, the factor(s) that oppose current flow is(are) _____.

    (a) resistance
    (b) inductive reactance
    (c) capacitive reactance
    (d) all of these

1.21 Ohm's Law Formula Circle

43. What's the voltage drop of two 12 AWG conductors (0.40 ohms) supplying a 16A load, located 100 ft from the power supply?

    Formula: $E_{vd} = I \times R$

    (a) 1.60V
    (b) 3.20V
    (c) 6.40V
    (d) 12.80V

44. What's the resistance of the circuit conductors when the conductor voltage drop is 7.20V and the current flow is 50A?

    Formula: R = E/I

    (a) 0.14 ohms
    (b) 0.30 ohms
    (c) 3 ohms
    (d) 14 ohms

1.22 PIE Formula Circle

45. What's the power loss in watts of a conductor that carries 24A and has a voltage drop of 7.20V?

    Formula: P = I x E

    (a) 175W
    (b) 350W
    (c) 700W
    (d) 2,400W

46. What's the approximate power consumed by a 10 kW heat strip rated 230V, when connected to a 208V circuit?

    Formula: $P = E^{2/R}$

    (a) 8.20 kW
    (b) 9.30 kW
    (c) 10.90 kW
    (d) 11.20 kW

1.23 Formula Wheel

47. The formulas in the power wheel apply to _____.

    (a) direct-current circuits
    (b) alternating-current circuits with unity power factor
    (c) direct-current circuits or alternating-current circuits
    (d) a and b

1.24 Using the Formula Wheel

48. When working any formula, the key to calculating the correct answer is following these four steps:

    Step 1: Know what the question is asking you to find.
    Step 2: Determine the knowns of the circuit.
    Step 3: Select the formula.
    Step 4: Work out the formula calculation.

    (a) True
    (b) False

1.25 Power Losses of Conductors

49. Power in a circuit can be either "useful" or "wasted." Wasted work is still energy used; therefore it must be paid for, so we call wasted work "_____."

    (a) resistance
    (b) inductive reactance
    (c) capacitive reactance
    (d) power loss

50. The total circuit resistance of two 12 AWG conductors (each 100 ft long) is 0.40 ohms. If the current of the circuit is 16A, what's the power loss of both conductors?

    Formula: $P = I^2 \times R$

    (a) 75W
    (b) 100W
    (c) 300W
    (d) 600W

51. What's the conductor power loss for a 120V circuit that has a 3 percent voltage drop and carries a current flow of 12A?

    Formula: $P = I \times E$

    (a) 43W
    (b) 86W
    (c) 172W
    (d) 1,440W

1.26 Cost of Power

52. What does it cost per year (at 8 cents per kWh) for the power loss of a 12 AWG conductor (100 ft long) that has a total resistance of 0.40 ohms and a current flow of 16A?

    Formula: Cost per Year = Power for the Year in kWh x $0.08

    (a) $33
    (b) $54
    (c) $72
    (d) $89

1.27 Power Changes with the Square of the Voltage

53. The voltage applied to a resistor dramatically affects the power consumed by that resistor because power is affected in direct proportion to the voltage.

    (a) True
    (b) False

54. What's the power consumed by a 10 kW heat strip that's rated 230V, if it's connected to a 115V circuit?

    Formula: $P = E^2/R$

    (a) 2.50 kW
    (b) 5 kW
    (c) 7.50 kW
    (d) 15 kW

UNIT 1

Challenge Questions

CHALLENGE QUESTIONS FOR UNIT 1—ELECTRICIAN'S MATH AND BASIC ELECTRICAL FORMULAS

PART A—ELECTRICIAN'S MATH

1.12 Kilo

1. One kVA is equal to _____.

   (a) 100 VA
   (b) 1,000V
   (c) 1,000W
   (d) 1,000 VA

PART B—BASIC ELECTRICAL FORMULAS

1.17 Conductance

2. Which of the following is the most conductive?

   (a) Bakelite
   (b) Oil
   (c) Air
   (d) Salt water

1.19 Ohm's Law

3. If the contact resistance of a connection increases and the current of the circuit (load) remains the same, then the voltage dropped across the connection will _____.

   (a) increase
   (b) decrease
   (c) remain the same
   (d) can't be determined

4. To double the current of a circuit when the voltage remains constant, the R (resistance) must be _____.

   (a) doubled
   (b) reduced by half
   (c) increased
   (d) none of these

5. An ohmmeter is being used to test a relay coil. The equipment instructions indicate that the resistance of the coil should be between 30 and 33 ohms. The ohmmeter indicates that the actual resistance is less than 22 ohms. This reading most likely indicates _____.

   (a) the coil is okay
   (b) an open coil
   (c) a shorted coil
   (d) a meter problem

1.23 Formula Wheel

6. To calculate the energy consumed in watts by a resistive appliance, you need to know _____ of the circuit.

   (a) the voltage and current
   (b) the current and resistance
   (c) the voltage and resistance
   (d) any of these pairs of variables

7. The power consumed by a resistor can be expressed by the formula $I^2 \times R$. If 120V is applied to a 10 ohm resistor, the power consumed will be _____.

   (a) 510W
   (b) 1,050W
   (c) 1,230W
   (d) 1,440W

8. Power loss in a circuit because of heat can be determined by the formula _____.

(a) P = R x I
(b) P = I x R
(c) P = I^2 x R
(d) none of these

9. The energy consumed by a 5 ohm resistor is _____ than the energy consumed by a 10 ohm resistor, assuming the current in both cases remains the same.

(a) more
(b) less

10. When a load rated 500W at 115V is connected to a 120V power supply, the current of the circuit will be _____. Tip: At 120V, the load consumes more than 500 watts, but the resistance of the load remains constant.

(a) 2.70A
(b) 3.80A
(c) 4.50A
(d) 5.50A

1.27 Power Changes with the Square of the Voltage

11. A 120V rated toaster will produce _____ heat when supplied by 115V.

(a) more
(b) less
(c) the same
(d) none of these

12. When a 100W, 115V lamp operates at 230V, the lamp will consume approximately _____.

(a) 150W
(b) 300W
(c) 400W
(d) 450W

13. A 1,500W resistive heater is rated 230V and is connected to a 208V supply. The power consumed by this load at 208V will be approximately _____.

(a) 1,225W
(b) 1,625W
(c) 1,750W
(d) 1,850W

14. The total resistance of a circuit is 10.20 ohms. The load has a resistance of 10 ohms and the wire has a resistance of 0.20 ohms. If the current of the circuit is 12A, then the power consumed by the circuit conductors (0.20 ohms) is approximately _____.

(a) 8W
(b) 29W
(c) 39W
(d) 45W