

Mike Holt's Illustrated Guide To

ELECTRICIAN'S MATH AND BASIC ELECTRICAL FORMULAS

Extracted from Mike Holt's Understanding Electrical Theory For NEC[®] Applications

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ABOUT THE AUTHOR

Mike Holt is an author, businessman, educator, speaker, publisher and *NEC*[®] expert. He has written hundreds of electrical training books and articles, founded three successful businesses, and has taught thousands of electrical *Code* seminars across the United States and internationally.



Mike's approach to electrical training is based on his own experience as an electrician, contractor, inspector and teacher. He's always felt a responsibility to his students and to the electrical industry to provide education beyond the scope of just passing an exam. This commitment, coupled with the lessons he learned at the University of Miami's MBA program, have helped him build one of the largest electrical training and publishing companies in the United States.

Mike's one-of-a-kind presentation style and his ability to simplify and clarify technical concepts explain his unique position as one of the premier educators and *Code* experts in the country. His passion for the electrical field drives his goal to increase electrical safety and improve lives.

Mike's commitment to pushing boundaries and setting high standards extends into his personal life. He's an eighttime Overall National Barefoot Waterski Champion with more than 20 gold medals, many national records, and he has competed in three World Barefoot Tournaments. In 2015, at the tender age of 64, he started a new adventure competitive mountain bike racing. Every day he continues to find ways to motivate himself, both mentally and physically.

Mike and his wife, Linda, reside in New Mexico and Florida, and are the parents of seven children and six grandchildren. As his life has changed over the years, a few things have remained constant: his commitment to God, his love for his family, and doing what he can to change the lives of others through his products and seminars.

> I dedicate this book to the Lord Jesus Christ, my mentor and teacher. Proverbs 16:3



ABOUT THIS PDF

This free PDF is extracted from *Mike Holt's Illustrated Guide to Understanding Electrical Theory*. In order to construct a building that will last into the future, a strong foundation is a prerequisite. Math and basic electrical concepts are very similar to the foundation of a building.

They 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 especially math, will help you understand why the *NEC* contains certain provisions.

You'll be amazed at how often your electrical studies return to the basics of math. 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. Our goal with this PDF extract is to introduce you, or re-introduce you, to the very basics.

The following are the topics covered with a brief description:

Unit 10–Basic Math

Understanding math is the foundation to becoming a successful electrician. Many people fear math, but as you work through this material you will see there is nothing to fear. In this unit you will learn:

- the difference between whole numbers and fractional numbers
- how to convert a percentage into a decimal to use as a multiplier
- the differences between a reciprocal, a square root, and squaring a number

Unit 11—Trigonometry

Trigonometry is the mathematical study of triangles, particularly right triangles. Trigonometry is used to determine three-phase voltage systems, size power factor correction capacitors, and determine alternating-current wire impedance. In this unit you will learn:

- what right triangles are
- what the Pythagorean Theorem is
- what sines, cosines, and tangents are

Unit 12–Ohm's Law

To understand electrical circuits, you must understand electrical terminology. In this unit you will learn:

- what electromotive force, intensity, and resistance are
- what voltmeters, ammeters, and ohmmeters are
- how to use the Ohm's Law formula

Unit 13–Watt's Law

Wattage is a measure of the amount of power that is being used in a circuit. In this unit you will learn:

- what Watt's Law is
- how to use Watt's Law
- what a wattmeter is

ADDITIONAL PRODUCTS TO HELP YOU LEARN

Mike Holt's Illustrated Guide to Electrical Theory

Why is it important? Whether you're a first-year apprentice still struggling to understand the difference between a volt or ampere, or a veteran journeyman trying to sharpen your troubleshooting skills, electrical theory is critical. Once you know the principles behind how electricity works, you will be ready to correctly apply the rules in the *National Electrical Code*[®] correctly to the work you do every day. Many people in the trade don't have the information they need to be successful; it's a mix of math, science, mechanics, the *National Electrical Code*, problem solving, and electrical safety that are all required to complete a successful installation.

For over 140 years, electricians have been installing electrical wiring in buildings to deliver power for convenience, safety, and productivity. Technology has changed a lot since Edison, Brush, and Westinghouse started installing lighting in the 19th century. Wiring systems have become more complex and every aspect of our daily life requires power to be accessible and reliable. In the business of progress some electricians may have lost sight of the fundamental concepts that make the electrical equipment we use work.

Recognizing a need to return to the basics, Mike's *Understanding Electrical Theory* textbook will take you on a journey that begins with the physics behind how electricity works all the way through topics and concepts that are relevant to everyone working in the electrical industry.

The installation practices of the electrical industry are controlled by the *National Electrical Code* so that people are protected from the hazards that arise from the use of electricity. The goal of this book is to bridge the gap between science, math, mechanics and *Code* to allow you to understand what you see and hear and also to read, understand and apply the *National Electrical Code* in the situations you encounter each day.

The writing style of this textbook, as with all of Mike Holt's products, is informative, practical, easy to read, and applicable for today's electrical professional. Also, just like all of Mike's textbooks, it contains hundreds of detailed graphics that support difficult concepts, facilitate understanding, and help in applying those concepts to real-world situations. To get the most out of this book you should answer the questions at the end of each unit.

The topics in this textbook will help you understand what electricity is, how it's produced and how it's used. You'll learn to perform basic electrical calculations necessary for everyday work, what those calculations tell you about how electricity flows in a circuit, and why it's always trying to return to its source.

This textbook explains why blinking lights, buzzing relays, hot wires and tripping breakers, all have one thing in common—they are the visible result of science and some basic math applied to an installation. If you don't understand how and why these things are happening, you're at a big disadvantage when it comes to troubleshooting and you may unintentionally place yourself or someone else in danger of injury or possibly even death. This makes it important for every electrician to learn the fundamentals of electricity to take themselves from being an installer who doesn't understand what's happening, to an electrician who can understand even the most complex situations.

In addition to the theory, *Code* topics will be introduced along the way, so that you understand why following *Codes* and standards is so important and when to apply different rules. For any references to the *National Electrical Code*, always compare what's being explained in this textbook to what the *Code* book says. This textbook is to be used along with the *NEC*, and not as a replacement for it.

This textbook, *Mike Holt's Illustrated Guide to Electrical Theory* teaches students everything they need to know about how electricity behaves. Starting from basic scientific principles, it explains the following:

- > Basics of matter and the origin of modern electricity
- How electricity is made
- Circuit types
- Electrical formulas and basic electrical math
- Magnetism and electromagnetism
- Practical applications of electricity (wiring systems and equipment)
- Motors, generators, and transformers
- Grounding and bonding
- How science and math apply to the *National Electrical Code* rules
- Electrical safety

CHAPTER

MATHEMATICS

Chapter 4—Mathematics

Unit 10–Basic Math

Understanding math is the foundation to becoming a successful electrician. Many people fear math, but as you work through this material you will see there is nothing to fear. In this unit you will learn:

- the difference between whole numbers and fractional numbers
- how to convert a percentage into a decimal to use as a multiplier
- the differences between a reciprocal, a square root, and squaring a number

Unit 11—Trigonometry

Trigonometry is the mathematical study of triangles, particularly right triangles. Trigonometry is used to determine three-phase voltage systems, size power factor correction capacitors, and determine alternating-current wire impedance. In this unit you will learn:

- what right triangles are
- > what the Pythagorean Theorem is
- what sines, cosines, and tangents are

UNIT 10 BASIC MATH

10.1 Introduction

Understanding mathematics is the foundation to becoming a successful electrical professional. As you work through this material you will see how easy math is. In this unit you will learn:

- > the difference between whole numbers and fractional numbers
- > how to convert a percentage into a decimal to use as a multiplier
- > the differences between a reciprocal, a square root, and squaring a number

10.2 Whole Numbers

Whole numbers are exactly what the term implies; these numbers do not contain any fractions, decimals, or percentages.

10.3 Fractional Numbers

Parts of a whole number are called "fractions" from the Latin word "fractus," meaning broken into parts. ►Figure 10–1





10.4 Decimal Numbers

(A) General. A decimal number is a number that is a fractional part of a number separated by a decimal point.

(B) Fractions Converted to Decimal Numbers. A fraction represents part of a whole number. If you use a calculator for adding, dividing, subtracting, or multiplying fractions, you need to convert the fraction to a decimal or whole number. To change a fraction to a decimal or whole number, divide the top number of the fraction by its bottom number. ▶Figure 10–2





(C) Number of Decimal Places. The decimal system places numbers to the right of a decimal point to indicate values that are a fraction of "one." For example, the first digit on the right of the decimal is one-tenth of a whole number, the second is one-hundredth of a whole number, and the third digit is one-thousandth of a whole number. ▶Figure 10–3



▶ Figure 10-3

If the decimal number is greater than "one," the whole number will be to the left of the decimal point such as 1.25, 1.732, and 2.50.

10.5 Percentages

(A) General. A percentage is another method used to display the value of a number. One hundred percent means the entire value; 50 percent means one-half of a value, and 25 percent means one-fourth of a value. ▶Figure 10-4



▶ Figure 10-4

(B) Convert a Percentage to a Decimal. For convenience in multiplying or dividing by a percentage, convert the percentage value to a whole number or whole number with a decimal, and then use that value for the calculation.

When changing a percent value to a decimal or whole number with a decimal, drop the percentage symbol and move the decimal point two places to the left. ▶Figure 10–5



▶ Figure 10-5

10.6 Parentheses

In a math problem, parentheses are used to group steps of mathematical functions together. Whenever numbers are in parentheses, complete the mathematical function within the parentheses before proceeding with the remaining math functions.

Parentheses Example

Question: What is the sum of 3 and 15 added to the product of 4 and 2?

Note: A "sum" is the result of adding numbers, and a "product" is the result of multiplying numbers.



10.7 Squaring a Number

Squaring (2) a number is the process of multiplying a number by itself.

Squaring a Number Example 1

 $8^2 = 8 \times 8$ $8^2 = 64$

Squaring a Number Example 2

12² = 12 ×12 12² = 144

10.8 Square Root

The square root ($\sqrt{}$) of a number is the number that, if squared (multiplied by itself), would equal the original number. You must use the square root key ($\sqrt{}$) on your calculator to perform this function.

Square Root Example 1

Question: What is the square root of 100? ▶ Figure 10–6



▶ Figure 10-6

Answer: (b) 10

Square Root Example 2

Question: What is the square root of 3?				
(a) 1.255	(b) 1.55	(c) 1.732	(d) 1.935	
Answer: (c) 1.7.	32			

10.9 Kilo

The letter "k" is the abbreviation for "kilo" which means "1,000." To convert a number that includes the "k," multiply the number by 1,000. To convert a number to a "k" value, divide the number by 1,000 and add "k" after the number.

Kilo Conversion Example 1

Question: What is the value of 8k?

(a) 8	(b) 800	(c) 4,000	(d) 8,000
Solution:			
8 × 1,000 = 8,	000		
Answer: (d) 8,	000		

Kilo Conversion Example 2

Question: What is the "k" value of 3,000?

(a) 0.30k	(b) 3k	(c) 30k	(d) 300k
Solution:			
k = 3,000/1,0 k = 3k	000		
Answer: (b) 3	lk		

10.10 Rounding

(A) General. There is no specific rule for rounding numbers, but; rounding to two or three "significant digits" should be sufficient for most electrical calculations. When rounding is desired, numbers below five are rounded down, while numbers five and above are rounded up.
▶Figure 10–7

Basic Math Rounding Answers <i>Theory 10.10(A)</i>
Round 0.1245 to three decimal numbers = 0.125 rounded up
Round 1.674 to two decimal numbers = 1.67 rounded down
Round 21.99 to a whole number = 22 rounded up Copyright 2022, www.MikeHolt.com
Round 367.20 to a whole number = 367 rounded down

▶ Figure 10-7

(B) Rounding Answers for Multiple-Choice Questions. When selecting an answer for a multiple-choice question, you need to round your answers in the same manner as the multiple-choice selections are given.

Rounding Answers for Multiple-Choice Questions Example

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

(b) 00 (c) 30 (d) 100

Solution:

12 + 17 + 28 + 40 = 97

The multiple-choice selections in this case are rounded off to the nearest "tens," so the answer is 100.

Answer: (d) 100

10.11 Surface Area of a Rectangle or Square

The surface area for a rectangle or square is calculated using the formula: Area = Length (L) \times Width (W)

Surface Area—Rectangle or Square Example 1

Question: What is the surface area of a bedroom that is 10 ft wide and 12 ft long? ▶Figure 10–8

(a) 10 sq ft (b) 50 sq ft (c) 80 sq ft (d) 120 sq ft





Solution:

Area = L × W Area = 12 ft × 10 ft Area = 120 sq ft

Answer: (d) 120 sq ft

Surface Area—Rectangle or Square Example 2

Question: What is the surface area of a house that is 30 ft wide and 40 ft long? ▶Figure 10–9

(a) 1,000 sq ft (b) 1,200 sq ft (c) 1,800 sq ft (d) 2,000 sq ft



▶ Figure 10-9

Solution:

Area = L × W

Area = 40 ft × 30 ft Area = 1,200 sq ft

Answer: (b) 1,200 sq ft

10.12 Surface Area of a Circle

The surface area of a circle is calculated using the formula: Area of a Circle = $\times r^2$

Use 3.14 for (pi).

The radius (r^2) is equal to one half the diameter of the circle.

Surface Area—Circle Example 1

Question: What is the surface area of an 8-in. pizza? ▶Figure 10–10

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



▶ Figure 10–10

Solution:

Area of a Circle = $\pi \times r^2$

 π = 3.14 Radius = ½ the diameter

Area = 3.14 × (8 in. × 0.50)² Area = 3.14 × 4 in.² Area = 3.14 × (4 in. × 4 in.) Area = 3.14 × 16 sq in. Area = 50 sq in.

Answer: (b) 50 sq in.

Note: If you prefer to use a calculator, then follow these steps:

Step 1: Find the radius (1/2 the diameter) of the circle by multiplying 8 in. by 0.50:

8 in. × 0.50 = 4 in.

- **Step 2:** Press the square " \times^2 " key = 16 sq in.
- *Step 3: Multiply 16 sq in. (Step 2) by 3.14. 16 sq in. × 3.14 = 50.26 sq in.*
- Step 4: Round to match the answer choices: 50 sq in.

Answer: (b) 50 sq in.

Surface Area—Circle Example 2

Question: What is the surface area of a 16-in. pizza? ▶ Figure 10–11

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





Solution:

Area of a Circle = $\pi \times r^2$

 π = 3.14 Radius = 1/2 the diameter

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

Answer: (c) 200 sq in.

Author's Comment:

As you can see, if you double the circle's diameter (an 8-in. pizza versus a 16-in. pizza), its area is increased by a factor of four. By the way, a large (or extra-large) pizza is always cheaper per square inch than a small one! ▶Figure 10–12

10.13 Volume

The volume of an enclosure is expressed in cubic inches (cu in. or in^3), and is determined by multiplying the enclosure's length, width, and depth together: **Volume = Length (L) × Width (W) × Depth (D)**.



Volume Example

Question: What is the volume of a 6 in. \times 6 in. \times 4 in. box? Figure 10–13

(a) 134 cu in. (b) 144 cu in. (c) 154 cu in. (d) 164 cu in.



Figure 10–13

Solution:

Volume = Length (L) × Width (W) × Depth (D)

 $Volume = 6 in. \times 6 in. \times 4 in.$ Volume = 144 cu in.

Answer: (b) 144 cu in.

10.14 Reciprocal

A reciprocal is the value of 1 divided by the number. All whole numbers shown as a fraction are over 1, a reciprocal flips the top number and puts it on the bottom for the mathematical function.

Reciprocal Example

Question: What is the reciprocal of 0.80?

(a) 0.80	(b) 1.10	(c) 1.25	(d) 1.50
Solution:			
1/0.80 = 1.25			
Answer: (c) 1.2	25		

10.15 Testing Your Answer

Never assume a mathematical calculation you have done is correct. Always do a "reality check" to be sure your answer makes sense. Even the best of us makes mistakes. You may have part of the problem jotted down incorrectly, or perhaps you pressed the wrong key on the calculator. Always examine your answer to see if it makes sense.

UNIT 11 TRIGONOMETRY

11.1 Introduction

Trigonometry is the mathematical study of triangles. Trigonometry is used to determine three-phase voltage systems, size power factor correction capacitors, and determine alternating-current wire impedance. In this unit you will learn:

- what right triangles are
- what the Pythagorean Theorem is
- what signs, cosines, and tangents are

11.2 Triangles

The basic things to remember when dealing with trigonometry, and specifically with math problems involving triangles, are that: Figure 11–1



▶ Figure 11-1

- A triangle has three sides: a = adjacent, b= opposite, and c = hypotenuse.
- (2) A triangle has three angles.
- (3) The total degrees of all angles in a triangle equals 180°.

11.3 Right Triangle

A right triangle is a triangle that contains a right angle. Important concepts concerning right triangles include: Figure 11-2



▶ Figure 11-2

- (1) One angle of the triangle is 90° and is called the right angle.
- (2) The sum of the other two angles in the triangle equals 90° .
- (3) The side of a right triangle that is opposite the right angle is called the "hypotenuse," which is the longest side of a right triangle and is represented by "c."

11.4 Pythagorean Theorem

The Pythagorean Theorem describes the mathematical relationship between the sides and angles of right triangles.

(1) You can calculate the length of the Hypotenuse side using: $c = \sqrt{(a^2 + b^2)}$

Example 1

Question: What is the length of the hypotenuse (c) of a right triangle where the opposite side (b) has a height of 32 ft, and the adjacent side (a) has a length of 24 ft? \rightarrow Figure 11–3



▶ Figure 11–3

Solution:

$$c=\sqrt{a^2+b^2}$$

a = Adjacent side = 24 ft b = Opposite Side = 32 ft c = Hypotenuse?

Hypotenuse = $\sqrt{(24^2 + 32^2)}$ Hypotenuse = $\sqrt{(576 + 1,024)}$ Hypotenuse = $\sqrt{1,600}$ Hypotenuse = 40 ft

Note: To solve for the square root of a number, use the square root key on your calculator.

Answer: (d) 40 ft

(2) You can calculate the length of the Opposite side using: $\mathbf{b} = \sqrt{(\mathbf{c}^2 - \mathbf{a}^2)}$

Example 2

Question: What is the length of the opposite (b) side of a right triangle where the adjacent side (a) has a length of 24 ft, and the hypotenuse (c) has a length of 40 ft? ► Figure 11-4





▶ Figure 11–4

Solution:

$$b=\sqrt{(c^2-a^2)}$$

a = Adjacent Side = 24 ft b = Opposite Side? c = Hypotenuse = 40 ft Opposite Side = $\sqrt{(40^2 - 24^2)}$ Opposite Side = $\sqrt{(1,600 - 576)}$ Opposite Side = $\sqrt{1,024}$ Opposite Side = 32 ft

Note: To solve for the square root of a number, use the square root key on your calculator.

Answer: (c) 32 ft

(3) You can calculate the length of the Adjacent side using: $a = \sqrt{(c^2 - b^2)}$

Example 3

Question: What is the length of the adjacent side (a) of a right triangle where the opposite side (b) has a height of 32 ft, and the hypotenuse (c) has a length of 40 ft? ▶ Figure 11–5

(a) 20 ft (b) 24 ft (c) 32 ft (d) 40 ft

Pytha	orean Theo	rem Adia	cent Side	
i yulaş	Theory 11.4	4 Example	3	Δ
$a = \sqrt{(a)}$	$(2^2 - b^2)$			
b = Opposite Side c = Hypotenuse = $a = \sqrt{(40^2 - 20^2)}$	e = 32 ft = 40 ft		1993 JUL	b = 33
$a = \sqrt{(40^{\circ} - 32^{\circ})}$ $a = \sqrt{(1,600^{\circ} - 1,02^{\circ})}$ $a = \sqrt{576}$	24)		1000 K	2 ft
a = Adjacent Side	e = 24 ft	- / °"		-
	Copyright 2022,	www.MikeHolt.com	a = 24 ft	



Solution:

$a=\sqrt{(c^2-b^2)}$

a = Adjacent Side?

- b = Opposite Side = 32 ft
- c = Hypotenuse = 40 ft

Adjacent Side = $\sqrt{(40^2 - 32^2)}$ Adjacent Side = $\sqrt{(1,600 - 1,024)}$ Adjacent Side = $\sqrt{576}$ Adjacent Side = 24 ft

Note: To solve for the square root of a number, use the square root key on your calculator.

Answer: (b) 24 ft

11.5 Practical Use of Trigonometry

Trigonometry can be used to find the height of a structure with just a carpenter's speed square and a calculator.

Speed Square Method of Measuring Height

- Step 1: Walk away from the structure until you can see the top without titling your head up.
- Step 2: Hold a speed square at eye level in your line of sight with the bottom of the speed square level with the ground.
- Step 3: Note the angle mark on the speed square that lines up with the top of the structure.
- Step 4: Measure (in feet) the distance you are standing away from the structure.
- **Step 5:** Find the approximate height of the structure using the formula:

Height = [Distance from Structure × (Tan of the Angle)] + Eye Height

► Example

Question: What is the height of a structure if you are standing 52 ft away from the structure, the angle on the speed square is 30° , and your eyes are 5 ft above the ground? Figure 11–6

(a) 25 ft (b) 35 ft (c) 45 ft (d) 55 ft

Solution:

Height = [Distance from Structure × (Tan of the Angle)] + Eye Height

Distance = 52 ft (given)

Tan of 30° is equal to 0.58 (from calculator) Eye Height = 5 ft (given)

Height of Structure = $[52 \text{ ft} \times (Tan \text{ of } 30^\circ)] + 5 \text{ ft}$ Height of Structure = $(52 \text{ ft} \times 0.58) + 5 \text{ ft}$ Height of Structure = 30 ft + 5 ftHeight of Structure = 35 ft

Answer: (b) 35 ft



▶ Figure 11-6

CHAPTER

OHM'S LAW AND WATT'S LAW

Chapter 5–Ohm's Law and Watt's Law

Unit 12–Ohm's Law

To understand electrical circuits, you must understand electrical terminology. In this unit you will learn:

- what electromotive force, intensity, and resistance are
- > what voltmeters, ammeters, and ohmmeters are
- how to use the Ohm's Law formula

Unit 13–Watt's Law

Wattage is a measure of the amount of power that is being used in a circuit. In this unit you will learn:

- what Watt's Law is
- how to use Watt's Law
- what a wattmeter is

UNIT 12 OHM'S LAW

12.1 Introduction

To understand electrical circuits, you must understand electrical terminology. In this unit you will learn:

- > what electromotive force, intensity, and resistance are
- what voltmeters, ammeters, and ohmmeters are
- how to use the Ohm's Law formula

12.2 The Electrical Circuit

All electrical circuits contain a power source necessary to produce the pressure to move electrons through the circuit wires to supply the load. Figure 12–1



▶ Figure 12–1

12.3 Electromotive Force (Pressure)

(A) General. In a circuit, the electrical pressure necessary for current flow is called "electromotive force" and is measured in the unit called a "volt" (V). Electromotive force is abbreviated as "EMF."

(1) **Residential Voltage.** In the United States, circuits for residential lights and receptacles operate at 120V, while large demanding loads like ranges, dryers, and air-conditioning equipment operate at 120/240V or 240V. ▶ Figure 12–2





(2) Commercial Voltage. In commercial and industrial occupancies, the voltage is often 277V for lighting and 480V for commercial loads like motors, air-conditioning units, and other equipment. ►Figure 12–3





(B) Voltmeter. Voltmeters are connected in parallel with the load and are used to measure the difference of potential between the two test leads. ▶Figure 12–4



▶ Figure 12-4

12.4 Circuit Resistance

(A) General. In a circuit, resistance is the opposition to current flow. Every component of an electrical circuit contains resistance, which includes the power source, the circuit wiring, and the load. Resistance is represented by the letter "R" or " Ω ," which is the ancient Greek letter Omega capitalized as "0," in honor of Georg Simon Ohm (1787–1854). ▶Figure 12–5



(B) Ohmmeters. Ohmmeters are used to measure resistance in the unit called an "ohm" (Ω). Figure 12–6



12.5 Circuit Intensity

(A) General. In an electrical circuit, the intensity of the current flow is measured in the unit called an "ampere," which is represented by the letter "I" for intensity. ▶Figure 12–7





(B) Current Measurement.

(1) Series-Connected Ammeters. Series-connected ammeters measure current in amperes and are connected in series with the circuit. Handheld series-connected ammeters are typically limited to a maximum current of 10 amperes. Figure 12-8





(2) Clamp-On Ammeter. Clamp-on ammeters measure the circuit current without opening the circuit wires as is required for a seriesconnected ammeter. In addition, these meters can measure current in the thousands of amperes.

A clamp-on ammeter has a sensor that is clamped around the wire and detects the rising and falling electromagnetic field being produced due to the ac flow through the wire. ▶ Figure 12-9



▶ Figure 12-9

12.6 Ohm's Law

(A) General. The German physicist Georg Simon Ohm (1787–1854) discovered that current is directly proportional to voltage and inversely proportional to resistance.

(1) Directly Proportional. Ohm's Law states that current is directly proportional to voltage. This means that current will increase in direct proportion to the voltage increase if the resistance of the circuit remains the same. If the voltage decreases and the circuit resistance remains the same, the circuit amperes will decrease in direct proportion to the voltage change. ▶ Figure 12-10



increase if the resistance remains the same. If the voltage decreases and the resistance remains the same, the current amperes will decrease in direct proportion to the voltage change



(2) Inversely Proportional. Ohm's Law also states that current is inversely proportional to resistance. This means that current will decrease in direct proportion to the increase in resistance if the voltage remains the same. If the resistance decreases and the voltage remains the same, then the circuit amperes will increase in direct proportion to the change in resistance. ►Figure 12–11



▶ Figure 12–11

(B) Ohm's Law Formula. The Ohm's Law formula demonstrates the relationship between the circuit intensity (I) or current measured in amperes, the electromotive force (E) or pressure measured in volts, and the resistance (R) measured in ohms as expressed in the formula: I = E/R.

The Ohm's Law formula can be transposed as follows:

I = E/R, Intensity = Electromotive Force/Resistance, Measured in Amperes

E = I × R, Electromotive Force = Intensity × Resistance, Measured in Volts

R = E/I, Resistance = Electromotive Force/Intensity, Measured in Ohms

12.7 Ohm's Law Formula Circle

To determine which formula in the Ohm's Law Formula Circle to use, place your finger on the unknown value for which you are looking. The two remaining variables "show" you the formula to be used. ►Figure 12–12





Electromotive Force E = I × R Example

Question: The voltage to a 192Ω resistor carrying 0.625A is . ▶ Figure 12–13







Solution:

The voltage of this circuit is determined by the formula $E = I \times R$.

E = **I** × **R** I = 0.625A R = 192Ω E = 0.625A × 192Ω **Answer:** (c) 120V

► Intensity I = E/R Example

Question: If a 120V source supplies a 192Ω light bulb, the current flow in the circuit will be _____. **Figure 12–14**





▶ Figure 12–14

Solution:

- Step 1: What is the question? What is "I"?
- Step 2: What do you know?

Voltage (E) = 120VResistance (R) = 192Ω

- Step 3: The formula to use is I = E/R.
- **Step 4:** The answer is $I = 120V/192\Omega$.
- **Step 5:** The answer is I = 0.625A.

Answer: (b) 0.625A

► Resistance R = E/I Example

Question: The resistance of an incandescent light bulb rated 120V drawing 0.625A is _____. ▶ Figure 12–15







Solution:

- Step 1: What is the question? What is "R"?
- Step 2: What do you know? Voltage (E) = 120V Current (I) = 0.625A
- **Step 3:** The formula to use is $\mathbf{R} = \mathbf{E}/\mathbf{I}$.
- **Step 4:** The answer is R = 120V/0.625A.
- **Step 5:** The answer is $R = 192\Omega$.

Answer: (c) 192Ω

UNIT 13 WATT'S LAW

13.1 Introduction

Wattage is a measure of the amount of power that is being used in a circuit. In this unit you will learn:

- what Watt's Law is
- how to use Watt's Law
- what a wattmeter is

13.2 Watt's Law

Power is defined as the rate of work measured by the unit called the "watt."

(A) Watt's Law Formula. Watt's Law states that power (P) in watts is equal to intensity (I) in amperes, times the electromotive force (E) in volts. ▶ Figure 13–1



The formula for Watt's Law can be transposed as follows:

 $P = I \times E$, Power = Intensity × Electromotive Force, Measured in Watts

I = P/E, Intensity = Power/Electromotive Force, Measured in Amperes

E = P/I, Electromotive Force = Power/Intensity, Measured in Volts

(B) Wattmeter. A wattmeter measures power by connecting it in parallel with the circuit to measure voltage, and in series with the circuit to measure amperes to calculate watts. ►Figure 13–2





Example

Question: A(An)) is used t	o measure power.	
(a) wattmeter	(b) voltmeter	(c) ohmmeter	(d) megger
Answer: (a) wat	ttmeter		

13.3 Power Formula Circle

The Power Formula Circle demonstrates the relationship between power, current, and voltage. To apply Watt's Law using the Power Formula Circle, place your finger on the unknown value for which you are looking and the two remaining variables "show" you the formula to be used. ▶Figure 13–3



Figure 13–3

Power (P) Example

Question: What is the power consumed by a circuit carrying 24A having a voltage drop of 7.20V? ▶Figure 13–4







Solution:

Step 1: What is the question asking you to find? What is the wire power loss? "P."

- Step 2: What do you know about the wires?
 - l = 24A E = 7.20 VD
- Step 3: The formula is $P = I \times E$.
- Step 4: Calculate the answer.
 - P = 24A × 7.20 VD P = 172.80W

Answer: (b) 175W

► Intensity (I) Example

Question: What is the current through a 7.50 kW heat strip rated 230V? ▶Figure 13–5





Solution:

- Step 1: What is the question? What is "I"?
- Step 2: What do you know?

Heat Strip Power Rating, P = 7.50 kW × 1,000 Heat Strip Power Rating, P = 7,500W Heat Strip Voltage Rating, E = 230V

- Step 3: The formula is I = P/E.
- Step 4: The answer is I = 7,500W/230V.
- Step 5: The answer is 32.61A.
- **Answer:** (b) 33A

13.4 Power Changes with the Square of the Voltage

The voltage applied to a load affects the power consumed by that load. The voltage can dramatically affect the power consumed by a load because power is a function of the square of the voltage. This means that if the voltage is doubled, the power will be four times the original value. If the voltage is decreased to 50 percent, the power will be 25 percent of its original value. ►Figure 13–6



▶ Figure 13–6

Power Equals the Square (²) of the Voltage Example 1

Question: What is the power consumed by a 10Ω load operating at 120V?

	a) 1,040W	(b) 1,400W	(c) 1,440W	(d) 1,444W
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Solution:

- $P = E^2/R$
- E = 120V (given)
- $R = 10\Omega$ (given)
- $P = (120V \times 120V)/10\Omega$ $P = 14,400/10\Omega$ P = 1,440W

Answer: (c) 1,440W

Power Equals the Square (²) of the Voltage Example 2

Question: What is the power consumed by a 10Ω load operating at 240V?

(a) 5,600W (b) 5,660W (c) 5,700W (d) 5,760W

Solution:

 $P = E^2/R$

E = 240V (given) $R = 10\Omega (given)$

 $P = (240V \times 240V)/10\Omega$ $P = 57,600/10\Omega$

P=5,760W

Answer: (d) 5,760W

Note: At 240V, the 10Ω resistor consumes four times the power as compared to the 120V circuit power.



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