Chapter 1
Basic Electrical Theory and Mathematics

Topics
1.0.0 Basic Mathematics
2.0.0 Electrical Terms and Symbols
3.0.0 Electrical Theory
4.0.0 Principles of DC
5.0.0 Principles of AC
6.0.0 Electrical Circuits
7.0.0 Electrical Circuit Computations
8.0.0 Constructing an Electrical Circuit

To hear audio, click on the box.

Overview

The origin of the modern technical and electronic Navy stretches back to the beginning of naval history, when the first navies were no more than small fleets of wooden ships, using wind and oars. The need for technicians then was restricted to a navigator and seamen who could handle the sails.

As time passed, the advent of the steam engine and electrical power sources signaled the rise of an energy sources more practical. With this technological advancement, the need for competent technicians increased. Today there is scarcely anyone in the United States Navy who does not use electrical or electronic equipment. This equipment is needed in systems of electric lighting and power, and intercommunications. As a Construction Electrician, your understanding and knowledge of basic electrical theory will able to conduct the Navy’s mission.

Basic mathematical skills are used everyday by Construction Electricians. A sound understanding of these basics prepares you for the more complex math skills you’re likely to use on construction projects, ranging from whole numbers, fractions, decimals, ratios, proportions, percentages, and square roots to measurements and calculations using geometric shapes.

Safety can be impacted by calculations you make for your project. For example, machinery electrical load requirements require precise calculations to prevent equipment damage and personnel injury or death.
## Objectives

When you have completed this chapter, you will be able to do the following:

1. Understand basic mathematics.
2. Identify electrical terms and symbols
3. Understand electrical theory.
4. Understand the electrical principles of Direct Current (DC).
5. Understand the electrical principles of Alternating Current (AC).
6. Understand the requirements and configurations of electrical circuits.
7. Understand the requirements of electrical circuit computations.
8. Understand the requirements of constructing an electrical circuit.

## Prerequisites

This course map shows all of the chapters in Construction Electrician Basic. The suggested training order begins at the bottom and proceeds up. Skill levels increase as you advance on the course map.

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NAVEDTRA 14026A
Features of this Manual

This manual has several features which make it easy to use online.

- Figure and table numbers in the text are italicized. The figure or table is either next to or below the text that refers to it.

- The first time a glossary term appears in the text, it is bold and italicized. When your cursor crosses over that word or phrase, a popup box displays with the appropriate definition.

- Audio and video clips are included in the text, with italicized instructions telling you where to click to activate it.

- Review questions that apply to a section are listed under the Test Your Knowledge banner at the end of the section. Select the answer you choose. If the answer is correct, you will be taken to the next section heading. If the answer is incorrect, you will be taken to the area in the chapter where the information is for review. When you have completed your review, select anywhere in that area to return to the review question. Try to answer the question again.

- Review questions are included at the end of this chapter. Select the answer you choose. If the answer is correct, you will be taken to the next question. If the answer is incorrect, you will be taken to the area in the chapter where the information is for review. When you have completed your review, select anywhere in that area to return to the review question. Try to answer the question again.
1.0.0 BASIC MATHEMATICS

1.1.0 Parts of a Whole Number

Whole numbers are made up of digits, which can be any numerical symbol from 0 to 9. Each digit of a whole number represents a place value, as shown in Figure 1-1. The number in this example is read as one million two hundred thirty-four thousand five hundred sixty-seven.

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Millions</td>
<td>Hundred Thousands</td>
<td>Ten Thousands</td>
<td>Thousands</td>
<td>Hundreds</td>
<td>Tens</td>
<td>Units</td>
</tr>
</tbody>
</table>

Figure 1-1 – Place values in whole numbers.

Every digit has a value that depends on its place, or location, in the whole number. In the example above, the place value of the 1 is one million; the place value of the 5 is five hundred.

Numbers can be positive or negative. Positive numbers are larger than zero and don’t usually have a positive sign (+) before them. Negative numbers are smaller than zero and always have a negative sign (-) before them. Zero is not positive or negative; it never has a positive or negative sign before it. Any whole number that doesn’t have a negative sign in front of it is a positive number.

1.2.0 Decimals

Decimals are numbers in the base 10 system, using any numerical symbol from 0 to 9. There are place values in decimal numbers that are similar to the place values in whole numbers, except that decimal numbers appear to the right of a decimal point and do not use comma separators. Place values in decimal numbers are shown in Figure 1-2.

<table>
<thead>
<tr>
<th></th>
<th>.</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Decimal Point</td>
<td>Hundredths</td>
<td>Thousandths</td>
<td>Ten Thousandths</td>
<td>Hundred Thousandths</td>
<td>Millionths</td>
<td></td>
</tr>
</tbody>
</table>

Figure 1-2 – Place values in decimal numbers.

As in whole numbers, decimal numbers have values that depend on their place in the number. In the example above, the place value of the 1 is one tenth, the place value of the 3 is three thousandths.

Operations with decimals are very similar to operations with whole numbers. The only difference is that you have to keep track of the decimal point.
1.2.1 Adding Decimals

When you add numbers containing decimals, you need to make sure you keep the
decimal points lined up. For example, if you add 12.34 to 5.678, they should look like
this when you add them:

\[
\begin{array}{c}
12.34 \\
+ 5.678 \\
\end{array}
\]

Make sure that you add each column of numbers, starting with the numbers that are
farthest right. In this case, the first number has no digit in the thousandths position, so it
can be treated as a zero:

\[
\begin{array}{c}
12.340 \\
+ 5.678 \\
\end{array}
\]

As you move left adding the columns, make sure to carry any numbers greater than 10.
When you add 4 and 7 in the hundredths column, the sum is 11. Record a 1 in the
hundredths column and carry a 1 to the tenths column as shown below:

\[
\begin{array}{c}
1 \\
12.340 \\
+ 5.678 \\
\end{array}
\]

When you add the tenths column, you have to add 3 and 6, and the 1 you carried from
the sum in the hundredths column. This will give you a sum of 10, so record the 0 in the
tenths column and carry a 1 to the units’ column as shown below:

\[
\begin{array}{c}
1 \\
12.340 \\
+ 5.678 \\
\end{array}
\]

Add the remaining numbers as you would any whole number. Remember to place the
decimal point between the units’ column and the tenths column, as shown below:

\[
\begin{array}{c}
12.340 \\
+ 5.678 \\
\end{array}
\]

1.2.2 Subtracting Decimals

Subtracting decimals is very similar to adding decimals. You need to line up the decimal
points as in addition. Subtracting 5.678 from 12.34 looks like this:

\[
\begin{array}{c}
12.37 \\
- 1.248 \\
\end{array}
\]
Since there are only 2 decimal points after the whole number in 12.34, we need to add a zero at the end so we can subtract the three decimal points in 5.678.

\[
\begin{align*}
12.370 \\
- 1.248 \\
\end{align*}
\]

You subtract columns the same way as you add them, starting with the farthest right column. In this case, you can't subtract 8 from 0, so you need to borrow from the hundredths column to be able to subtract from 10, as shown below:

\[
\begin{align*}
6 \\
12.37^10 \\
- 1.248 \\
2 \\
\end{align*}
\]

You now have 6 to subtract 4 from, since you borrowed 1 from 7. The rest of the numbers subtract normally, as shown below:

\[
\begin{align*}
6 \\
12.37^10 \\
- 1.248 \\
11.122 \\
\end{align*}
\]

### 1.2.3 Multiplying Decimals

When you multiply numbers with decimals, there is a two step process. First you multiply the numbers as if they were whole numbers. Then you place the decimal point in the correct location. The example below shows the product of 1.2 and 3.4, before the decimal is placed.

\[
\begin{align*}
1.2 \\
x 3.4 \\
\hline \\
408 \\
\end{align*}
\]

To get the correct location for the decimal point, count the number of decimal places in each number and add the number of decimal places. In this case, each number has one decimal place, so the product will have two decimal places. The product of the equation is 4.08.

### 1.2.4 Dividing Decimals

When you divide numbers with decimals, there is a four step process.

1. Convert the divisor to a whole number. A divisor of .1 becomes 2.
2. Convert the dividend by the same number of decimal places as the divisor. In this case, 2.34 becomes 23.4.
3. Divide the two numbers as shown below.

\[
\begin{array}{c}
11.7 \\
23.4 \\
\hline
2 \\
2 \\
3 \\
2 \\
14 \\
14 \\
0 \\
\end{array}
\]

4. Place the decimal according to the number of decimal places in the dividend.

\[
\begin{array}{c}
11.7 \\
23.4 \\
\hline
\end{array}
\]

1.3.0 Fractions

A fraction is a part of a whole. Fractions are usually written as two numbers separated by a slash, such as 1/2. The slash means the same thing as the division sign (÷), so 1/2 = 1 ÷ 2. Figure 1-3 shows a whole triangle shaded blue and a triangle with one half (1/2) shaded blue.

![Figure 1-3 – Whole and half triangles.](image)

The bottom number of a fraction is called the **denominator** and tells how many parts the whole is being divided into. The top number of a fraction is called the **numerator** and tells how many of the parts are being used. In the example of 1/2, 2 is the denominator and 1 is the numerator. The denominator and numerator are also known as the terms of the fraction.

Equivalent fractions are different fractions which mean the same amount. For example, 1/2 is an equivalent fraction to 2/4, 10/20, and 25/50.

1.3.1 Reducing Fractions to Their Lowest Terms

Fractions shown with different numbers can have the same value. Fractions are easier to work with when they are at the lowest terms possible. For example, it is easier to work with the fraction 1/2 than it is to work with the equivalent fraction 17/34. To reduce a fraction to its lowest terms, there are three steps.

1. Determine what the largest number is that will divide evenly into both the numerator and the denominator. If the only number that will divide evenly into both numbers is 1, the fraction is at its lowest terms.
2. Divide both the numerator and denominator by the number you determined in Step 1.

3. For the fraction 8/32, the largest number that evenly divides both the numerator 8 and the denominator 32 is 8. Reducing the fraction to its lowest terms looks like this:

\[
\frac{8}{32} \div \frac{8}{8} = \frac{1}{4}
\]

### 1.3.2 Comparing Fractions and Finding the Lowest Common Denominator

Comparing fractions is simple if the two fractions have the same denominator. In this case, the fraction with the larger numerator is larger than the fraction with the smaller numerator.

Most fractions that you need to compare won’t have the same denominator. You need to convert them to the same denominator to compare them. The simplest way to convert fractions to the same denominator is to multiply their denominators to get a **common denominator**, and then convert each fraction to the resulting denominator. For example, if you are comparing 3/4 to 5/7, you would convert and compare them as shown below.

1. Find the common denominator.
   
   \[4 \times 7 = 28\]

2. Convert each fraction to the common denominator.
   
   \[
   \frac{3}{4} \times \frac{7}{7} = \frac{21}{28}
   \]
   
   \[
   \frac{5}{7} \times \frac{4}{4} = \frac{20}{28}
   \]

3. Compare the fractions. You find that 3/4 is larger than 5/7.

Just as you can find the lowest terms for single fractions, you can find the **lowest common denominator** for multiple fractions.

1. Reduce both fractions to their lowest terms.

2. Determine the lowest common multiple for the denominators. You may find that one denominator is a multiple of the other. For example, if you are comparing 1/4 and 3/8, the denominator 8 is a multiple of the denominator 4.

3. Convert the fractions to equivalent fractions with the common denominator.
   
   \[
   \frac{1}{4} \times \frac{2}{2} = \frac{2}{8}
   \]
   
   \[
   \frac{3}{8} \times \frac{1}{1} = \frac{3}{8}
   \]

4. Compare the fractions. You find that 1/4 is smaller than 3/8.

### 1.3.3 Adding Fractions

Sometimes you calculate a number where the numerator is larger than the denominator. This is called an **improper fraction**. You can convert an improper fraction to a whole number and a fraction, which is known as a **mixed number**. Start by adding the fractions as you would normally. To add 5/7 to 3/4:

1. Find the common denominator.
   
   \[7 \times 4 = 28\]

2. Convert each fraction to the common denominator.
\[ \frac{5}{7} \times \frac{4}{4} = \frac{20}{28} \]
\[ \frac{3}{4} \times \frac{7}{7} = \frac{21}{28} \]

3. Add the numerators of the fractions, and place the sum over the common denominator. Do NOT add the denominators.
\[ \frac{20}{28} + \frac{21}{28} = \frac{41}{28} \]

4. Convert the improper fraction to a mixed number.
\[ 41 \div 28 = 1 \text{ with a remainder of } 13 \text{ or } 1 \frac{13}{28} \]
The remainder becomes the numerator for the fraction portion of the mixed number. The resulting mixed number is \(1 \frac{13}{28}\).

### 1.3.4 Subtracting Fractions

When you need to subtract measurements that include fractions on construction projects, it is very similar to adding fractions. If the denominators of the fractions are the same, subtract the numerators, place the result over the denominator, and reduce the resulting fraction to its lowest terms. If the denominators are not the same, follow these steps.

1. Write out the equation.
   \[ \frac{3}{4} - \frac{1}{8} = x \]
2. Determine the common denominator for the fractions you need to subtract. For the fractions \(\frac{3}{4}\) and \(\frac{1}{8}\), the common denominator is \(4 \times 8 = 32\).
3. Convert the fractions to equivalent fractions with the common denominator.
   \[ \frac{3}{4} \times \frac{8}{8} = \frac{24}{32} \]
   \[ \frac{1}{8} \times \frac{4}{4} = \frac{4}{32} \]
4. Subtract the numerators of the fractions, and place the result over the common denominator. Do NOT subtract the denominators.
   \[ \frac{24}{32} - \frac{4}{32} = \frac{20}{32} \]
5. Reduce the resulting fraction to its lowest terms.
   \[ \frac{20}{32} \div \frac{4}{4} = \frac{5}{8} \]

Sometimes you need to subtract a fraction from a whole number. To do this you need to convert the whole number to an equivalent fraction, and then make your subtraction. In this example we’ll subtract \(\frac{5}{8}\) from 1.

1. Write out the equation.
   \[ -\frac{5}{8} = x \]
2. Convert the whole number to an equivalent fraction.
   \[ 1 \times \frac{8}{8} = \frac{8}{8} \]
3. Subtract the numerators of the fractions, and place the result over the common denominator. Do NOT subtract the denominators.
   \[ \frac{8}{8} - \frac{5}{8} = \frac{3}{8} \]
4. Reduce the resulting fraction to its lowest terms. In this case the result is already in its lowest terms.

1.3.5 Multiplying Fractions
Multiplying fractions is fairly simple, since you don’t need to worry about finding a common denominator. When you read or hear that you need to find a part of a number, such as 3/8 of 5/6, it means you need to multiply the numbers using the steps below.

1. Write out the equation.
   \[ \frac{3}{8} \times \frac{5}{6} = x \]
2. Multiply the numerators.
   \[ 3 \times 5 = 15 \]
3. Multiply the denominators.
   \[ 8 \times 6 = 48 \]
4. Reduce the resulting fraction to its lowest terms.
   \[ \frac{15}{48} \div \frac{3}{3} = \frac{5}{16} \]

In this case, 3 is the largest number that can be evenly divided into both the numerator and the denominator. You may find it easier to work with the fractions if you reduce them to their lowest terms before you multiply them.

1.3.6 Dividing Fractions
Dividing fractions is very similar to multiplying fractions, except that you invert or flip the fraction you are dividing by. Use the following steps to divide \( \frac{7}{8} \) by \( \frac{1}{4} \).

1. Write out the equation.
   \[ \frac{7}{8} \div \frac{1}{4} = x \]
2. Invert the fraction you are dividing by.
   \( \frac{1}{4} \) becomes \( \frac{4}{1} \)
3. Convert the division sign (\( \div \)) to a multiplication sign (\( \times \)) and write the new equation.
   \[ \frac{7}{8} \div \frac{1}{4} \text{ becomes } \frac{7}{8} \times \frac{4}{1} \]
4. Multiply the numerators.
   \[ 7 \times 4 = 28 \]
5. Multiply the denominators.
   \[ 8 \times 1 = 8 \]
6. Reduce the resulting fraction to its lowest terms.
   \[ \frac{28}{8} \div \frac{4}{4} = \frac{7}{2} \]
7. Convert the improper fraction to a mixed number.
   \[ 3 \frac{1}{2} \]
1.4.0 Conversions – Fractions and Decimals

There will be times when you need to convert numbers so that all of the numbers you are working with are in the same format. The most common conversions you will work with are from fractions to decimals and from decimals to fractions.

1.4.1 Converting Fractions to Decimals

To convert a number from a fraction to a decimal, divide the numerator by the denominator.

1.4.2 Converting Decimals to Fractions

There are three steps to convert a decimal to a fraction. The decimal .125 can be converted to a fraction as follows:

1. Place the number to the right of the decimal point in the numerator.
   \[ \frac{125}{1000} \]

2. Count the number of decimal places in the number. Place this number of zeros following a 1 in the denominator.
   \[ \frac{125}{1000} \]

3. Reduce the fraction to its lowest terms.
   \[ \frac{125}{1000} ÷ \frac{125}{125} = \frac{1}{8} \]

1.4.3 Converting Inches to Decimal Equivalents in Feet

Sometimes you will need to convert measurements in inches to decimal equivalents in feet.

\[ .052 ÷ 2 = .05 \]

The results are that 6 inches converts to 0.5 foot.

1.5.0 Ratios and Proportions

1.5.1 Ratios

A ratio is a comparison of two numbers, which can be expressed in three ways. A comparison of the numbers 1 and 2 can be expressed as follows:

\[ 1:2 \]
\[ \frac{1}{2} \]
\[ 1 \text{ to } 2 \]

One place where ratios come into play for Builders is Rule 42 for concrete mixes. This rule specifies a ratio of 1:2:4 for cement, sand, and aggregates.

Ratios can be used to calculate the quantities of materials needed for a project. If your specifications call for a 1:2:4 concrete mix with 2-inch coarse aggregates, you use Rule 42 to figure the material amounts.

Add 1:2:4, which gives you 7. Then compute your material requirements as follows:

\[ 42 \text{ cu ft } ÷ 7 = 6 \text{ cu ft} \]
\[ 1 \times 6 = 6 \text{ cu ft of cement} \]
\[ 2 \times 6 = 12 \text{ cu ft of sand} \]
4 x 6 = 24 cu ft of coarse aggregates

1.5.2 Proportions
A proportion is an equation showing a ratio on each side. The equation shows that the two ratios are equal, as shown below:

1:2 = 2:4

You will usually work with proportions to figure an unknown number on one side of the equation. If you have a ratio of 1:2 and need to figure the equivalent ratio of n:8, there are three steps.

1. Write out the proportion.
   2:4 = n:8 OR 2/4 = n/8

2. Use the cross product.
   4 x n = 2 x 8
   4n = 16

3. Solve the proportion.
   n = 16/4
   n = 4

1.6.0 Percentages
A percentage is a number expressed as a fraction of 100. You will usually see percentages with the percent sign, as in 35%.

You can calculate the percentage of a material that has been used in two steps.

1. Divide the used amount by the initial amount.
2. Multiply the result by 100.

If you had an initial supply of 300 sheets of plywood and you have used 80 of them, you calculate the percent used as follows:

80/300 = .27
.27 x 100 = 27%

If you need to know what percent you have remaining, you subtract the percent used from 100, as follows:

100 – 27 = 73%

If you have not calculated the percent used, you can still calculate the percent remaining with two steps.

1. Calculate the amount remaining.
   300 – 80 = 220

2. Calculate the percent remaining.
   220/300 = .73
   .73 x 100 = 73%
1.7.0 Conversions – Percentages and Decimals

1.7.1 Converting Percentages to Decimals
Convert a decimal to a percentage by multiplying the decimal by 100. If you need the percentage equivalent of .74, perform the following calculation:

\[ .74 \times 100 = 74\% \]

1.7.2 Converting Decimals to Percentages
Convert a decimal to a percentage by multiplying the decimal by 100. If you need the percentage equivalent of .74, perform the following calculation:

\[ .74 \times 100 = 74\% \]

1.8.0 Square Roots
The square root of a number is a value that, multiplied by itself, gives the original number. In other words, if you have a value \( x \), the square root \( r \) is a number such that \( r^2 = x \). A simple example is the square root of 9, which is 3.

There is a table in Appendix I of NAVEDTRA 14139 Mathematics, Basic Math, and Algebra called Squares, Cubes, Square Roots, Cube Roots, Logarithms, and Reciprocals of Numbers that you can use to look up a square root. If that resource or a calculator with a square root function is not available, there are several methods of calculating a square root. The simplest of these methods is called the Babylonian Method, which is repeated until you get as close to the square root as you need to. This example will calculate the square root of 8.

1. Estimate a number that you think is close to the square root. For this example, use 3 as the estimate.
2. Divide the number you are trying to calculate the square root of by your estimate.
   \[ 8/3 = 2.67 \]
3. Add that number to your estimate.
   \[ 3 + 2.67 = 5.67 \]
4. Divide the sum by 2.
   \[ 5.67/2 = 2.835 \]
5. Test your result by multiplying the number by itself. If the result is accurate enough, great! Stop here.
6. If the number is not accurate enough, use the result as your new estimate. In our example, when 2.835 is squared, the result is 8.037225. Using a second round brings us to a possible square root of 2.828, with a result of 7.997584.
7. Repeat these steps until you have as accurate a result as you need.

1.9.0 Metric System
The metric system is a decimal-based system of units. We will focus on units of weight, length, volume, and temperature.
1.9.1 Units of Weight

The standard metric unit of mass is the gram. Table 1-1 shows units of mass, their equivalents in grams, and the abbreviations for the units of mass.

**Table 1-1 – Metric Units of Mass.**

<table>
<thead>
<tr>
<th>Unit of Mass</th>
<th>Equivalent in Grams</th>
<th>Abbreviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 milligram</td>
<td>0.001 gram</td>
<td>mg</td>
</tr>
<tr>
<td>1 centigram</td>
<td>0.01 gram</td>
<td>cg</td>
</tr>
<tr>
<td>1 decigram</td>
<td>0.1 gram</td>
<td>dg</td>
</tr>
<tr>
<td>1 gram</td>
<td>1 gram</td>
<td>g</td>
</tr>
<tr>
<td>1 kilogram</td>
<td>1000 grams</td>
<td>kg</td>
</tr>
</tbody>
</table>

1.9.2 Units of Length

The standard metric unit of length is the meter. Table 1-2 shows units of length, their equivalents in meters, and the abbreviations for the units of length.

**Table 1-2 – Metric Units of Length.**

<table>
<thead>
<tr>
<th>Unit of Length</th>
<th>Equivalent in Meters</th>
<th>Abbreviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 millimeter</td>
<td>0.001 meter</td>
<td>mm</td>
</tr>
<tr>
<td>1 centimeter</td>
<td>0.01 meter</td>
<td>cm</td>
</tr>
<tr>
<td>1 decimeter</td>
<td>0.1 meter</td>
<td>dm</td>
</tr>
<tr>
<td>1 meter</td>
<td>1 meter</td>
<td>m</td>
</tr>
<tr>
<td>1 kilometer</td>
<td>1000 meters</td>
<td>km</td>
</tr>
</tbody>
</table>

1.9.3 Units of Volume

The standard metric unit of volume is the liter. Table 1-3 shows units of volume, their equivalents in liters, and the abbreviations for units of volume.

**Table 1-3 – Metric Units of Volume.**

<table>
<thead>
<tr>
<th>Unit of Volume</th>
<th>Equivalent in Liters</th>
<th>Abbreviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 milliliter</td>
<td>0.001 liter</td>
<td>ml</td>
</tr>
<tr>
<td>1 centiliter</td>
<td>0.01 liter</td>
<td>cl</td>
</tr>
<tr>
<td>1 deciliter</td>
<td>0.1 liter</td>
<td>dl</td>
</tr>
<tr>
<td>1 liter</td>
<td>1 liter</td>
<td>l</td>
</tr>
<tr>
<td>1 kiloliter</td>
<td>1000 liters</td>
<td>kl</td>
</tr>
</tbody>
</table>
1.9.4 Units of Temperature

The standard metric unit of temperature is the degree Celsius. The boiling point of water at sea level is 100°Celsius, or 100°C. The freezing point of water at sea level is 0°Celsius, or 0°C. A day with a temperature of 30°C is considered hot.

1.9.5 Metric Conversion

There will be times when you need to convert to metric equivalents of measurements. Table 1-4 shows conversions for some of the most common measurements.

**Table 1-4 – Conversion to Metric Equivalents.**

<table>
<thead>
<tr>
<th>English Symbol</th>
<th>When You Know</th>
<th>Multiply By</th>
<th>To Find</th>
<th>Metric Symbol</th>
</tr>
</thead>
<tbody>
<tr>
<td>LENGTH</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>in</td>
<td>inches</td>
<td>25.4</td>
<td>millimeters</td>
<td>mm</td>
</tr>
<tr>
<td>ft</td>
<td>feet</td>
<td>0.305</td>
<td>meters</td>
<td>m</td>
</tr>
<tr>
<td>yd</td>
<td>yards</td>
<td>0.914</td>
<td>meters</td>
<td>m</td>
</tr>
<tr>
<td>mi</td>
<td>miles</td>
<td>1.61</td>
<td>kilometers</td>
<td>km</td>
</tr>
<tr>
<td>AREA</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>in²</td>
<td>square inches</td>
<td>645.2</td>
<td>square millimeters</td>
<td>mm²</td>
</tr>
<tr>
<td>ft²</td>
<td>square feet</td>
<td>0.0903</td>
<td>square meters</td>
<td>m²</td>
</tr>
<tr>
<td>yd²</td>
<td>square yards</td>
<td>0.836</td>
<td>square meters</td>
<td>m²</td>
</tr>
<tr>
<td>ac</td>
<td>acres</td>
<td>0.405</td>
<td>hectares</td>
<td>ha</td>
</tr>
<tr>
<td>mi²</td>
<td>square miles</td>
<td>2.59</td>
<td>square kilometers</td>
<td>km²</td>
</tr>
<tr>
<td>VOLUME</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>fl oz</td>
<td>fluid ounces</td>
<td>29.57</td>
<td>milliliters</td>
<td>mL</td>
</tr>
<tr>
<td>gal</td>
<td>gallons</td>
<td>3.785</td>
<td>liters</td>
<td>L</td>
</tr>
<tr>
<td>ft³</td>
<td>cubic feet</td>
<td>0.028</td>
<td>cubic meters</td>
<td>m³</td>
</tr>
<tr>
<td>yd³</td>
<td>cubic yards</td>
<td>0.765</td>
<td>cubic meters</td>
<td>m³</td>
</tr>
<tr>
<td>MASS</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>oz</td>
<td>ounces</td>
<td>28.35</td>
<td>grams</td>
<td>g</td>
</tr>
<tr>
<td>lb</td>
<td>pounds</td>
<td>0.454</td>
<td>kilograms</td>
<td>kg</td>
</tr>
<tr>
<td>T</td>
<td>short tons (2000 lb)</td>
<td>0.907</td>
<td>Megagrams (“metric ton”)</td>
<td>Mg (or “t”)</td>
</tr>
<tr>
<td>TEMP</td>
<td>°F</td>
<td>(F-32) x 5/9 or (F-32)/1.8</td>
<td>Celsius</td>
<td>°C</td>
</tr>
</tbody>
</table>
1.10.0 Using Measuring Tools

Measuring tools are a key part of a Builder’s toolkit. You will most likely use a **standard (English) ruler**, an **architect’s scale**, and a **metric ruler**, as shown in Figure 1-4. There are conversions between standard and metric measurements, but you will have better results if you measure with the appropriate ruler, such as a standard ruler when you are working in the United States.

**Standard (English) Ruler**

**Architect’s Scale**

**Metric Ruler**

Figure 1-4 – Types of measurement tools.

1.10.1 Using a Standard Ruler

A standard ruler is divided into inches and feet. Inches are divided into fractions of an inch, including halves, fourths, eighths, and sixteenths, as represented in Figure 1-5. There are some rulers that are further divided into thirty-seconds and sixty-fourths of an inch.

Figure 1-5 – Inch divided into 16ths.

An English or metric ruler is read from left to right. The arrow in Figure 1-6 is at 2 and 5/16 inches.

Figure 1-6 – Measuring on an English ruler.
1.10.2 Using the Architect’s Scale

An architect’s scale is used to read all plans except site plans. It measures interior and exterior dimensions for structures and buildings, including rooms, walls, doors, and windows. Table 1-5 shows scales that are generally grouped in pairs using the same dual-numbered index line.

<table>
<thead>
<tr>
<th>Table 1-5 – Common architect scale groupings.</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image.png" alt="Image" /></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Description</th>
<th>Abbreviation</th>
<th>Ratio Equivalent</th>
<th>Description</th>
<th>Abbreviation</th>
<th>Ratio Equivalent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Three inches to the foot</td>
<td>3&quot; = 1’ 0’”</td>
<td>1:4</td>
<td>One and one half inches to the foot</td>
<td>1 1/2&quot; = 1’ 0’”</td>
<td>1:8</td>
</tr>
<tr>
<td>One inch to the foot</td>
<td>1” = 1’ 0’”</td>
<td>1:12</td>
<td>One half inch to the foot</td>
<td>1/2&quot; = 1’ 0’”</td>
<td>1:24</td>
</tr>
<tr>
<td>Three quarters inch to the</td>
<td>3/4&quot; = 1’ 0’”</td>
<td>1:16</td>
<td>Three eighths inch to the foot</td>
<td>3/8&quot; = 1’ 0’”</td>
<td>1:32</td>
</tr>
<tr>
<td>Three sixteenths inch to the</td>
<td>3/16&quot; = 1’ 0’”</td>
<td>1:64</td>
<td>Three thirty-twoths inch to the foot</td>
<td>3/32&quot; = 1’ 0’”</td>
<td>1:128</td>
</tr>
</tbody>
</table>

Numbers on architect scales can be read from left to right or right to left, depending on which scale you are using. Unlike standard rulers, the 0 point on an architect’s scale is not at the end of the measuring line. Any numbers below 0 represent fractions of one foot.

Determine what scale you need to use from the drawing you are working with. Find the matching scale on one of the ends of the architect’s scale you are using. If the scale you need is shown on the left of the architect’s scale, measure and read from left to right. If the scale you need is shown on the right of the architect’s scale, measure and read from right to left. Figure 1-7 shows measurements on the 1/8” = 1’ 0” and 1/4” = 1’ 0” scales.

This diagram shows a reading of 21’ 4” on the one eighth inch to the foot scale, reading from left to right. Notice that the numbers for this scale are the top set, reading 0, 4, 8, 12, etc. The feet are measured to the right of the zero on the scale; the inches are measured to the left of the zero on the scale. The numbers in the bottom set, reading 46, 44, 42, 40, etc. are for the one quarter inch to the foot scale.
This diagram shows a reading of 6’ 2” on the one fourth inch to the foot scale, reading from right to left. Notice that the numbers for this scale are the bottom set, reading 0, 2, 4, 6, etc. The feet are measured to the left of the zero on the scale; the inches are measured to the right of the zero on the scale. The numbers in the top set, reading 56, 60, 64, 72, etc. are for the one eighth inch to the foot scale.

A metric ruler is divided into millimeters and centimeters, which makes it fairly easy to read, as shown in Figure 1-8.

![Image 1-8](image1)

Figure 1-8 – Metric ruler divided into centimeters and millimeters.

Centimeters are shown as larger lines with numbers; millimeters are shown as smaller lines. One millimeter is 1/10th of a centimeter.

### 1.11.0 Construction Geometry

Measurements of shapes are a basic part of construction you will use every day. You should be familiar with measuring basic shapes like circles, triangles, squares, and rectangles.

#### 1.11.1 Angles

Two straight lines that meet at a common point form an angle. The point where the lines meet to form the angle is called a vertex. Angles are measured with a tool called a protractor, using degrees. There are many different types of angles, as shown in Figure 1-9.

![Image 1-9](image2)

**1.11.1.1 Acute Angle**

An acute angle measures between 0 and 90 degrees. Common acute angles measure 30, 45, and 60 degrees.

**1.11.1.2 Right Angle**

A right angle measures 90 degrees. The two lines that form a right angle are perpendicular to each other. This is the angle that is used most in construction. It is indicated in drawings by the symbol \( \rightangle \).
1.11.1.3 Obtuse Angle
An obtuse angle measures between 90 and 180 degrees. Common obtuse angles are 120, 135, and 150 degrees.

1.11.1.4 Straight Angle
A straight angle measures 180 degrees, a flat line.

1.11.1.5 Adjacent Angles
Adjacent angles are right next to each; they share a vertex and one side.

1.11.1.6 Opposite Angles
Opposite angles are formed by two straight lines that cross; they are always equal.

Figure 1-9 – Types of angles.

1.11.2 Shapes
Your work in construction involves common geometric shapes. These shapes include rectangles, squares, triangles, and circles, as shown in Figure 1-10.

1.11.2.1 Rectangle
A rectangle is a four sided shape with all four angles being right angles. All four angles in a rectangle add up to 360°. A rectangle has two pairs of parallel sides, which makes a rectangle a parallelogram. In a rectangle, the longer sides define the length of the rectangle; the shorter sides define the width.

1.11.2.2 Square
A square is a special rectangle with four right angles and equal length parallel sides. Each angle in a square is 90°, totaling 360° for all four angles.
1.11.2.3 Triangle

A triangle is a basic shape in geometry, with three sides or edges, also known as line segments. A triangle is a polygon with three corners, or vertices. The three angles of a triangle always add up to 180°.

Types of triangles are classified by the relative lengths of their sides.

- **Right Triangle** – A right triangle has one 90°, or right, angle. The longest side of the right triangle is opposite the right angle, and is called the hypotenuse. The other two sides of the right triangle are called the legs.

- **Equilateral Triangle** – An equilateral triangle has all three sides of an equal length; this makes it equiangular. It is also equilinear, which means that all three of its internal angles are the same 60°.

- **Isosceles Triangle** – An isosceles triangle has two sides of equal length. An isosceles triangle also has two angles equal to each other; the angles opposite the equal sides.

- **Scalene Triangle** – A scalene triangle has three sides of different lengths. The angles inside a scalene triangle are also all different.
1.11.2.4 Circle
A circle is a simple closed curve where every point on the curved line is the same distance from the center. A circle always measures 360°. The *circumference* of a circle is the outside perimeter of the circle. The *diameter* of a circle is a line straight through the circle from one point on the outside to a point directly opposite on the outside. The *radius* of a circle is the distance from the center of the circle to a fixed point on the outside of the circle. The radius is half of the diameter of the circle.

*Figure 1-10 – Types of shapes.*

1.11.3 Area of Shapes
Area is a measurement of the two-dimensional size of a surface. Calculations for the area of shapes differ according to the type of shape. See Figure 1-11.

1.11.3.1 Rectangle
The area (A) of a rectangle is the product of its length (L) and its width (W). This is expressed as

\[ A = L \times W \]

If you need to paint a wall that is 12 feet long and 8 feet high, you calculate the area of the wall based on a rectangle with a length of 12 feet and a width of 8 feet.

\[ A = 12 \text{ ft} \times 8 \text{ ft} = 96 \text{ ft}^2 \]

1.11.3.2 Square
The area of a square is the product of the length (L) of its sides.

\[ A = L^2 \]
1.11.3.3 Triangle

The area of a triangle is the base times the height times 0.5.

\[ A = B \times H \times 0.5 \]

If you need siding to cover a triangular shape 4 feet wide and 3 feet high, you calculate the area of the triangular shape based on a triangle with a base of 4 feet and a height of 3 feet.

\[ A = 4\text{ft} \times 3\text{ft} \times 0.5 = 6\text{ft}^2 \]

1.11.3.4 Circle

The area enclosed by a circle is the radius of the circle squared multiplied by \( \pi \). The radius is one half of the diameter of the circle.

\[ A = R^2 \times \pi \]

If you need sealer to cover a circular driveway 16 feet in diameter, you calculate the area of the driveway based on a radius of 8 feet.

\[ A = 8^2 \text{ft} \times 3.14 \]
\[ A = 64\text{ft} \times 3.14 = 201\text{sq ft} \]

Figure 1-11 – Area of shapes.

1.11.4 Volume of Shapes

The volume of any solid, liquid or gas is how much three-dimensional space it occupies. Volumes of straight edged and circular shapes are calculated using arithmetic formulae, based on length, width, and height. Volume is measured in cubic units, as shown in Table 1-6 and Figure 1-12.

Table 1-6 – Cubic Measurements.

<table>
<thead>
<tr>
<th>Cubic Measure</th>
<th>Full Expression</th>
<th>Abbreviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cubic inch</td>
<td>1 inch \times 1 inch \times 1 inch</td>
<td>inch(^3)</td>
</tr>
<tr>
<td>Cubic foot</td>
<td>1 foot \times 1 foot \times 1 foot</td>
<td>foot(^3)</td>
</tr>
<tr>
<td>Cubic yard</td>
<td>1 yard \times 1 yard \times 1 yard</td>
<td>yard(^3)</td>
</tr>
<tr>
<td>Cubic centimeter</td>
<td>1 centimeter \times 1 centimeter \times 1 centimeter</td>
<td>centimeter(^3)</td>
</tr>
<tr>
<td>Cubic meter</td>
<td>1 meter \times 1 meter \times 1 meter</td>
<td>meter(^3)</td>
</tr>
</tbody>
</table>
1.11.4.1 Rectangular Shape

The volume of a rectangular shape is the length times the width times the depth.

\[ V = L \times W \times D \]

If you need to figure how many cubic yards of concrete to order for a slab 15 feet long and 5 feet wide and 4 inches thick, you calculate the volume of the slab based on a length of 15 feet, a width of 10 feet, and a depth of 4 inches. This will take several steps.

Convert inches to feet.

\[ 4 \text{ in} \div 12 \text{ in/ft} = 0.33 \text{ ft} \]

Figure the volume.

\[ V = 15 \text{ ft} \times 10 \text{ ft} \times 0.33 \text{ ft} = 49.5 \text{ cu ft} \]

Convert cubic feet to cubic yards.

\[ 49.5 \text{ cu ft} \div 27 \text{ cu ft/cu yd} = 1.83 \text{ cu yd} \]

1.11.4.2 Cube

The volume of a cube, which is based on a square, is similar to the volume of a rectangle; it is the length times the width times the depth. The only difference is that all three measurements are the same in a cube.

If you need to figure how many cubic yards of concrete to order for a support member measuring 6 feet cubed, you calculate the volume of the support member based on the length, width, and depth each being 6 feet.

Figure the volume.

\[ V = 6 \text{ ft} \times 6 \text{ ft} \times 6 \text{ ft} = 216 \text{ cu ft} \]

Convert cubic feet to cubic yards.

\[ 216 \text{ cu ft} \div 27 \text{ cu ft/cu yd} = 8 \text{ cu yd} \]
1.11.4.3 Cylinder

The volume of a cylinder, which is based on a circle, is \( \pi \) times the radius\(^2\) times the height of the cylinder. Another way to think of this is the area of the circle times the height of the cylinder.

If you need to figure how many cubic yards of concrete to order for a column 2 feet in diameter and 12 feet high, you calculate the volume of the column as follows:

Figure the area of the circle.
\[
A = \pi \times 2 \text{ ft} = 6.28 \text{ sq ft}
\]

Figure the volume of the cylinder.
\[
V = 6.28 \text{ sq ft} \times 12 \text{ ft} = 75.36 \text{ cu ft}
\]

Convert cubic feet to cubic yards.
\[
75.36 \text{ cu ft} \div 27 \text{ cu ft / cu yd} = 2.79 \text{ cu yd}
\]

1.11.4.4 Triangular Shape

The volume of a triangular shape is 0.5 times the base times the height times the depth. Another way to think of this is the area of the triangle times the height of the structure.

If you need to figure how many cubic yards of concrete to order for a triangular shape with a base of 2 feet, a height of 2 feet, and 16 feet long, you calculate the volume of the triangular shape as follows:

Figure the area of the triangle.
\[
A = 0.5 \times 2 \text{ ft} \times 2 \text{ ft} = 2 \text{ sq ft}
\]

Figure the volume of the triangular shape.
\[
V = 2 \text{ sq ft} \times 16 \text{ ft} = 32 \text{ cu ft}
\]

Convert cubic feet to cubic yards.
\[
32 \text{ cu ft} \div 27 \text{ cu ft / cu yd} = 1.19 \text{ cu yd}
\]

Figure 1-12 – Volume of shapes.

2.0.0 ELECTRICAL TERMS and SYMBOLS

2.1.0 General Information

In order to discuss the theory of electricity, it is necessary to first define some electrical terms.
2.1.1 Voltage
Voltage is described as the pushing force behind electricity. Voltage may also be referred to as Difference of Potential, Electromotive Force (EMF), or Electrical Pressure. Think of electricity as water running through a hose. The pressure (voltage) is what causes the water (current) to flow out of the end of the hose. The unit of measurement for voltage is the volt, and the letter for voltage is "V" except when used in formulas to calculate voltage. In this case the letter “E” is used to denote Electromotive Force. Voltage is calculated by multiplying current and resistance; this formula is known as Ohm’s Law. As an example E = I x R. Refer to Figure 1-13.

2.1.2 Current
Current is the actual movement of electrons through the conductor. In relationship to the water hose, current is the water running through the hose. In order for current to flow, there must be a complete path. If there are opens in the circuit, then no current will flow. The unit of measurement for current flow is the ampere (amp), and the letter for amperage is "A" except when used in formulas to calculate current. In this case the letter “I” is used to denote current. Ohm’s Law is also used to calculate current. Current is calculated by dividing voltage by resistance. As an example I = E ÷ R. Refer to Figure 1-13.

2.1.3 Resistance
Resistance is defined as the opposition to current flow. Some materials offer more resistance than others. An example of this is rubber. Rubber has more resistance in comparison to copper because of the difference in their molecular construction. Materials with little resistance are known as conductors because current can flow through them easily.

Materials with high resistance are used as insulators because current can not flow through them as easily. Examples of low resistance materials are copper and aluminum. A few examples of high resistance materials are rubber, porcelain, fiberglass and dry wood.

The unit of measurement for resistance is the ohm, and the symbol for resistance is "Ω". When used in formulas to calculate resistance the symbol “R” is used to denote Resistance. Ohm’s Law is also used to calculate resistance. Resistance is calculated by dividing voltage by current. As an example R = E ÷ I. Refer to Figure 1-13.

2.1.4 Power
Power is the rate at which work is done, or the usable electricity produced or consumed. The unit of measurement is the watt, and the letter designator is "P". Electrical appliances are measured in watts. Wattage is calculated by multiplying volts and amperes; this formula is known as the power law. As an example P = E x I. Refer to Figure 1-13.
2.2.0 Types of Electricity

2.2.1 Direct Current
Current flowing in only one direction is referred to as Direct Current. The letters "DC" represent direct-current. A battery produces direct-current. The voltage source behind this direct-current has the same polarity all the time. The current flow is from negative to positive. Refer to Figure 1-14.

2.2.2 Alternating Current
Most of the time you will be working with Alternating Current. The letters "AC" represent alternating current. It is called AC because it alternates (changes) directions. An AC cycle is made up of one positive and one negative alternation. AC flows one way for half a cycle then the other way for half a cycle. In the United States, we use 60 cycles per second (60 Hertz (Hz). Since there is one positive and one negative alternation per cycle, 60 Hz AC changes directions 120 times per second. Refer to Figure 1-15.

2.2.3 Electrical Components
As a Construction Electrician you will be required to interpret a variety of electrical drawings, schematics and wiring diagrams in the accomplishment of your day-to-day duties. These products will be used to provide you with essential information required to install, maintain and troubleshoot electrical circuits as well as show the manner in which electrical devices within the circuit are connected. Since it would be impossible to make pictorial drawings of each electrical component shown within any of these products, the components are represented by use of symbols. See Table 1-7.

It should be noted that a symbol is a simplified picture of the device represented. Without these symbols, electrical drawings, schematics and wiring diagrams would cover many pages. It would also require many hours of drafting time as well as hours of piecing drawings together to come up with a useful product. A list of some of the most
commonly used electrical symbols, terms for electrical components along with a brief description of what the component does are provided as follows:

<table>
<thead>
<tr>
<th>NAME</th>
<th>DESCRIPTION</th>
<th>SYMBOL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wire or Conductor</td>
<td>Path for current flow</td>
<td></td>
</tr>
<tr>
<td>Wires Connected</td>
<td>Two or more electrical paths of current flow that are connected so that the same voltage is present in both wires.</td>
<td></td>
</tr>
<tr>
<td>Wires Not Connected:</td>
<td>Conductors of current flow insulated from each other. They may cross each other but are not electrically connected. Current cannot flow from one conductor to the other.</td>
<td></td>
</tr>
<tr>
<td>Switch (single pole, single throw)</td>
<td>Switch is used to change the direction or completely stop current flow by opening or closing a circuit. A single pole, single throw (SPST) has one pivot point and one set of contacts.</td>
<td></td>
</tr>
<tr>
<td>Switch (single pole, double throw):</td>
<td>Used to control two different circuits when they both can't be energized at the same time.</td>
<td></td>
</tr>
<tr>
<td>Switch (single pole, double throw):</td>
<td>Used to control two circuits at the same time. When one circuit is energized, so is the other one.</td>
<td></td>
</tr>
<tr>
<td>Lamp</td>
<td>An electrical device that converts electrical energy into light.</td>
<td></td>
</tr>
<tr>
<td>Motor:</td>
<td>Converts electrical energy into mechanical energy.</td>
<td><img src="image" alt="motor" /></td>
</tr>
<tr>
<td>Rheostat:</td>
<td>A variable resistor used to limit current flow. Resistance can be between 0-100% of the resistor rating.</td>
<td><img src="image" alt="rheostat" /></td>
</tr>
<tr>
<td>Coil:</td>
<td>A length of wire looped with very limited space between the loops.</td>
<td><img src="image" alt="coil" /></td>
</tr>
</tbody>
</table>
3.0.0 ELECTRICAL THEORY

A basic understanding of electrical theory is important in order to understand your job as a construction electrician. Scientists, such as Faraday, Ohm, Lenz, and Kirchoff have found that electricity seems to behave in a constant and predictable manner in a given condition. These scientists observed and described the predictable characteristics of electricity and electric current in the form of certain rules. These rules are often referred to as "laws". Although we cannot see the electrons in motion, through experiments and observation we know how they behave. By learning the laws applying to the behavior of electricity and by understanding the methods of producing, controlling, and using it, electricity may be "learned" without ever actually seeing it.

3.1.0 General Background Information

3.1.1 Atomic Structure

The smallest building blocks of matter are called atoms. All atoms are made of three basic parts: the proton, the neutron, and the electron (See Figure 1-16). Different numbers and arrangements of protons, neutrons, and electrons give atoms different properties which make up any one of the more than 100 fundamental substances known as elements.

3.1.1.1 Nucleus

The nucleus is positively charged. It is the center part of an atom and contains protons and neutrons. It accounts for 99.9% of an atom's weight. Refer to Figure 1-16 for nucleus position.

3.1.1.1.1 Proton

The proton is positively charged. The atomic number of an atom is equal to the number of protons in the atom. Atoms have the same number of protons and electrons, making atoms electrically neutral.

3.1.1.2 Neutron

The neutron has no electrical charge making it neutral. Lighter elements have about the same number of protons and neutrons. Heavier elements have more neutrons than protons. Since they have no electrical charge, they do not make the material more positive or negative.

3.1.1.2 Electrons

Electrons are at various distances from the nucleus and are arranged in energy levels called shells or rings. Electrons occupy almost the entire volume of an atom, but electrons themselves account for only a small fraction of an atom's mass. Largely, the number of electrons in its outermost ring (commonly known as the valence ring) determines the chemical behavior of an atom. When atoms combine and form molecules, electrons in the outermost shell are either transferred from one atom to
another or shared between atoms in a process known as covalent bonding. Uniform movement of electrons in a specific direction is known as current flow and can be utilized to perform work. Electron flow is fundamental to electrical theory.

### 3.1.1.2.1 Electrical Charge

Electrons are negatively charged particles. Ordinarily, an atom has an equal number of electrons and protons. Each electron carries one unit of negative charge and each proton carries one unit of positive charge. As a result, the atom is electrically neutral. If an atom gains electrons, it becomes negatively charged. If it loses electrons, it becomes positively charged. Electrically charged atoms are called ions.

### 3.1.1.2.2 Valence Ring

The outermost ring determines whether a material is going to be a conductor or an insulator. Conductors allow current to flow through them with little or no resistance. Conductors are used to move electricity from place to place. Insulators do not allow electricity to readily flow though them and have a very high resistance. Insulators are used to contain electricity. Examples of both conductive and insulating materials are as follows:

<table>
<thead>
<tr>
<th>Conductors</th>
<th>Insulators</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silver</td>
<td>Dry Air</td>
</tr>
<tr>
<td>Copper</td>
<td>Glass</td>
</tr>
<tr>
<td>Aluminum</td>
<td>Mica</td>
</tr>
<tr>
<td>Zinc</td>
<td>Rubber</td>
</tr>
<tr>
<td>Brass</td>
<td>Asbestos</td>
</tr>
<tr>
<td>Iron</td>
<td>Bakelite</td>
</tr>
</tbody>
</table>

Atoms may contain anywhere from one to eight electrons in their valance ring. Materials with 1 or 2 electrons in their valance ring allow room for other electrons to pass through easily. These materials make good conductors. Materials with more electrons in the valance ring (7 or 8) make good insulators. Materials having 4 or 5 electrons in the valance ring make for good semiconductors. A semiconductor is a material that is neither a good conductor nor a good insulator. See Figure 1-17.

Some of the electrons of certain metallic atoms are so loosely bound to the nucleus that they are comparatively free to move from atom to atom. Thus, a very small force or amount of energy will cause such electrons to be removed from the atom and become free electrons. These free electrons constitute the flow of an electric current in electrical conductors. The best conductors are silver, copper, and aluminum, in that order. However, copper is used more extensively because it is less expensive.

In contrast to good conductors, some substances such as rubber, glass, and dry wood have very few free electrons. In these materials, large amounts of energy must be expended in order to break the electrons loose from the influence of the nucleus. Substances containing very few free electrons are called Poor Conductors, Non Conductors, or Insulators.
Actually, there is no sharp dividing line between conductors and insulators, since electron flow is known to exist to some extent in all matter. You as a Construction Electrician will simply use the best conductors as wires to carry current and the poorest conductors as insulators to prevent the current from being diverted from the wires.

3.1.2 Effects of Current Flow

Current flow has four effects that are used in various ways: magnetism, heat, chemical action, and physical shock.

3.1.2.1 Magnetism

Whenever current flows in a conductor, it produces a magnetic field around that conductor. Most manufactured magnets are created using this principle. This principle is also incorporated into devices called electromagnets. Electromagnets serve many useful purposes, such as relays, circuit breakers and electric motors.

3.1.2.2 Heat

Remember that current flow is the movement of free electrons. In essence, atomic structures are being rearranged. Electrons are being pulled off one atom and attached to another in a kind of domino effect. This action causes friction, which develops the heat effect that is a characteristic of current. Have you ever unplugged an appliance and felt the warmth of the cord? If so, you have felt one of the effects of current.

3.1.2.3 Chemical Action

Current produces a chemical action when it flows through a liquid. For example, when an electric current is passed through water, the water molecules will begin to separate into hydrogen and oxygen gas. This effect of current makes possible such things as the electroplating process, the operation of batteries and many other useful processes.

3.1.2.4 Physical Shock

As a Construction Electrician you must always stay alert to your work and your surroundings. This will help prevent current from affecting you with a physical shock. Under certain circumstances, as little as 0.1 amperes could stop your heart. A common 60 watt light bulb uses five times that much current.

3.1.3 Relationship of Voltage, Current, and Resistance

All electrical circuits are a combination of three electrical properties: voltage, current and resistance. Voltage is defined as the force that causes free electrons to move in a conductor. Current can be defined as a uniform movement of electrons in a specified direction and resistance simply stated is the opposition to current flow. No matter what the property each will have a direct bearing on the other and behave according to predictable principles.

3.1.3.1 Voltage to Current

Voltage has a major effect on current. As voltage rises, current rises. Think of voltage like water pressure, the higher the water pressure the more water comes out and the further it will jump. Electricity works the same way. Higher voltage pushes more current. The higher the voltage the farther current will jump. Since it is easy to change voltage, it is the most common means of regulating current flow.
3.1.3.2 Resistance to Voltage

Increasing resistance will cause voltage to drop. This is hard to do because to add resistors the circuit has to be physically changed.

3.1.3.3 Resistance to Current

Anything that uses electrical power offers resistance. Resistance is opposition to current flow. Think of resistance as blockage in the water pipe. As resistance rises, current flow drops. There are four main factors that affect resistance:

- **Temperature**: As heat rises, resistance increases. In a cool conductor, it is easier for the electrons to flow in one direction. When the conductor heats up, the electrons are more agitated and this causes increased resistance. The cooler a conductor the less resistance. The hotter the conductor the more resistance.

- **Length**: The longer the conductor the more resistance it will have. The shorter the conductor the less resistance it will have.

- **Material**: As stated earlier, the type of material will affect its ability to conduct electricity. The relative resistance of conductors with the same length and cross-sectional area are given in the following list with silver as a standard of 1 and the remaining metals arranged in order of ascending resistance.

- **Cross sectional Area**: Just as a larger water pipe can carry more water, a larger conductor can carry more current. The larger the conductor, the less resistance to current flow. The smaller the conductor, the more resistance to current flow.

Although all conductors are designed to have low resistance, they still have some resistance depending on the four factors stated above.

3.1.4 Ohm’s Law

Ohm’s Law states that current is directly proportional to the voltage and inversely proportional to the resistance. This means that if voltage is increased, current will increase at the same rate. If voltage is decreased, current will decrease.

Ohm’s Law applies to resistance as well. CURRENT IS INVERSELY PROPORTIONAL TO RESISTANCE. In other words, if applied voltage remains the same, and resistance is increased, the current will decrease. If the resistance is decreased, the current will increase. Higher resistance allowed less current to go through. This means that if the resistance is increased, the current is decreased. If the resistance is decreased, the current is increased.

This can be represented by a formula as follows:

- \[ V = I \times R \]
- \[ I = \frac{V}{R} \]
- \[ R = \frac{V}{I} \]

Where:

- \( V \) = Voltage in volts (V)
- \( I \) = Current in amperes (A)
- \( R \) = Resistance in ohms (Ω)
Test your Knowledge (Select the Correct Response)

1. What type of charged particles are associated with electrons?
   A. Neutral  
   B. Positive  
   C. Negative  
   D. Canceling

2. Which of the following statements is true?
   A. The shorter the conductor the more resistance it will have  
   B. The longer the conductor the less resistance it will have  
   C. The more bends in a conductor the more resistance it will have  
   D. The shorter the conductor the less resistance it will have

4.0.0 PRINCIPLES of DC

As a Construction Electrician, you will encounter DC while working on DC motors and most electronic equipment found in fire alarm, intrusion detection and traffic signal systems. While alternating current (AC) is better for transmitting electricity, DC is used extensively to provide a constant direct power source. This section will introduce you to the general uses, generating sources and characteristics of DC.

4.1.0 Identifying Principles of DC

Direct-current is used to power most electronic components found in fire alarm, traffic signal, and security alarm systems. It is also used in control circuits for motors and battery backup systems for high voltage substations and emergency lighting systems. Two sources of DC are batteries and DC generators.

4.1.1 Sources of DC

4.1.1.1 Battery

The most common source of DC is the battery. Batteries convert chemical energy to electrical energy. As an electrician, batteries are used as an emergency power source for substations and emergency lights. There are two basic types of batteries: primary and secondary cell. Both types of batteries require a chemical reaction to create electricity.

4.1.1.2 Symbol

The symbol for a single cell battery is shown on the left side of Figure 1-18. The longer vertical line on the far left represents the positive terminal and the shorter vertical line on the right represents the negative terminal. By adding additional long and short vertical lines a
multi-celled battery can be represented. The battery symbol on the right side of Figure 1-18 is representative of a four cell battery.

4.1.1.3 Chemical Action
A battery consists of three main components: a positive electrode, a negative electrode, and an electrolyte. General-purpose batteries use strips of zinc and copper for the electrodes and sulfuric acid and water for the electrolyte. When the electrodes are connected by a conductor through a load a chemical reaction occurs that causes one electrode to lose electrons giving it a positive charge and the other electrode to gain electrons giving it a negative charge as shown in Figure 1-19.

4.1.1.4 Primary Cell
Flashlight batteries are common examples of a primary cell. The primary cell is usually a dry cell, so called because it uses a paste for the electrolyte. The primary cell is a “one time” use battery, and is properly disposed of when the stored electrical charge is fully depleted.

4.1.1.5 Secondary Cell
Secondary cells are also known as rechargeable batteries, storage batteries or accumulators. They are different from primary cells in that they can be recharged and reused. This is accomplished by applying current to the battery in the opposite direction of normal current flow. The chemical reaction is reversed to restore the active material, which is depleted during normal operation. Secondary cells are often found in emergency lights, exit lights and vehicle batteries to name a few. Depending on its use, the secondary cell could be a dry cell as described earlier, or the higher maintenance wet cell. Wet cells use a liquid for the electrolyte and need regular maintenance.

4.1.2 DC Generator
Another method of obtaining DC is through use of a DC generator. A generator converts mechanical energy to electrical energy with the help of magnetism. In order to create electricity with a generator you need three things: a conductor, a magnetic field and relative motion (the conductor is moving relative to the magnetic field.) When a conductor is moved through a magnetic field an electrical energy in the form of voltage and current is produced.
4.1.2.1 Conductor

When the conductor is moved through the magnetic field, the electrons inside the conductor are excited and move in a specific direction providing current flow. The conductor is often a coil of wire instead of the simplified conductor shown in Figure 1-20.

4.1.2.2 Magnetic Field

The magnetic field must be present in order to produce the current flow in the conductor. Either a permanent magnet or an electromagnet can produce the magnetic field. The stronger the magnetic field the stronger the current flow.

4.1.2.3 Relative Motion

In order to produce electricity you must have relative motion. The idea is that you must cut magnetic lines of force with the conductor. The conductor must be moved perpendicular to the magnetic lines of force. If the conductor were moved parallel to the magnetic field, the effect would be retarded. Notice in Figure 1-20, View A that moving the conductor in one direction gives electron flow to the right as shown by the small black arrows. In Figure 1-20, View C, the conductor is moving in the opposite direction, changing the direction of electron flow.

4.1.3 Split Rings

A DC generator uses split rings. A simplified diagram of a DC generator is illustrated in Figure 1-21. A loop of wire represents the conductor, which rotates through the magnetic field. The ends of the loop terminate in two copper half-rings, called split rings, which are insulated from each other. Fixed brushes make contact with the copper split rings to conduct electricity to the external circuit. The loop is rotated in a clockwise direction. In position A, the conductors of the loop are moving parallel with the field; since the conductor is not cutting the lines of force, there is no voltage produced.

At position B, the loop is moving at right angles to the field and voltage is at maximum. At position C, the loop is again moving parallel to the field and voltage is at zero. At position D, the loop is cutting across the field and voltage is again at maximum. Notice that the sides of the loop have now reversed themselves, but voltage to the meter is still in the same direction.

As the brushes are stationary, they deliver direct-current because either conductor in contact with a particular brush has the same direction of motion across the field. Check the black brush in Figure1-21 at positions B and D; notice that the sides of the loop change, but the brushes remain stationary.
With two brushes riding on the split rings to carry the current on an external circuit, you have an elementary DC generator producing electrical current. An AC generator is almost identical. The difference is a DC generator uses split rings to give direct-current while the slip rings of an AC circuit give you alternating current. AC generation will be covered extensively in the next block of instruction.

4.2.0 Characteristics of DC

DC is generally easier to understand than AC because there are fewer variables. Most DC circuits are purely resistive. Electrical properties of a DC circuit are easily determined using Ohm’s Law.

4.2.1 Flows in One Direction

In a DC circuit, it is important for you to understand that direct-current flows only in one direction. Direct-current always flows from negative to positive. Direction of current flow is referred to as polarity. When wiring any DC circuit you must ensure that you wire the polarity correctly; in other words, make sure the current is flowing in the direction required. If you disregard polarity, you could damage the power source, the circuit, or cause injury to yourself. To wire a DC circuit correctly refer to the manufacturer’s instructions and strictly observe the position of the positive and negative terminals.

4.2.2 Relationship of Voltage, Current, and Resistance (Ohm’s Law)

As previously stated, Ohm’s Law of Electricity applies to DC circuits as well. Ohm’s Law states that for any circuit the electric current is directly proportional to the voltage and inversely proportional to the resistance. Another way of remembering the relationship of these electrical properties is that the current is DIRECTLY proportional to the applied voltage and INVERSELY proportional to the resistance – simply stated this means that if the voltage is increased, the current is increased. If the voltage is decreased, the current is decreased, if applied voltage remains the same, and resistance is increased, the current will decrease. If the resistance is decreased, the current will increase.
Test your Knowledge (Select the Correct Response)
3. Which of the following is NOT part of a standard battery?
   A. Positive electrode  
   B. Gap Suppressor  
   C. Negative electrode  
   D. Electrolyte

5.0.0 PRINCIPLES of AC

5.1.0 Principle Definitions

5.1.1 AC vs. DC

5.1.1.1 Direct Current
Direct current is a constant output that does not vary with respect to time. In other words, as time passes after you turn the power on, the output stays at the same level. Figure 1-22 shows the relationship between volts (vertical axis) and time (horizontal axis). Note that for DC, assuming that the switch is turned on at the zero time mark, the value of 120 volts stays constant as time passes. A good example of a DC power source is the common automobile battery.

5.1.1.2 Alternating Current
AC power sources do not have a fixed polarity. As the polarity of the power source changes, the direction of the current it produces also changes. Looking at Figure 1-22 again, and assuming that the switch is turned on at the zero mark for the AC source, note that the voltage does not reach the 120 volts level until some time has passed. Once it reaches this level, it starts descending again to zero. After this point, the voltage drops below zero until it reaches the negative 120 volts level. Then it goes back to the zero level to continue alternating between the positive 120 volts value and the negative 120 volts value.

5.1.2 Generation of AC

5.1.2.1 Conditions Needed
As was the case with DC generation (using a DC generator), a conductor, a magnetic field, and relative motion must also exist to generate AC.

Figure 1-23 is similar to the DC generator. The wire loop rotating within the magnetic field generates the power as it breaks through the magnetic lines of force. The rings collect this power and it is displayed in the measuring device connected to them. The difference between the DC generator and this AC generator is that the rings are not split for the AC generator, they are continuous. This causes one side of the loop to be in constant contact with one brush only. When, for example, the black side of the wire loop moves from its vertical position to the horizontal position, it causes the needle in the
measuring device to move from zero to a maximum value. As the wire loop continues to rotate from the horizontal position to the vertical inverted position, the needle in the measuring device moves back to zero. The next rotation again causes the needle to move to a maximum value but in the opposite direction. Imagine the wire loop rotating at several revolutions per minute—the needle in the measuring device would be pointing right and left alternately. In a practical generator the wire loop, or windings, rotate at thousands of revolutions per minute. A measuring device with a needle like the one depicted in Figure 1-23 would not be able to move that fast and it would only vibrate at the zero mark.

![Diagram of an AC generator](image)

**Figure 1-23 – AC generator.**

Measuring devices for AC are designed specifically for that purpose and are constructed so that the pointing needle will point to the maximum value without alternating. Modern equipment use digital displays that eliminate the mechanical needle movement. One of these instruments is called an oscilloscope. It is used to display the voltage, current or both at the same time in the form of waves, sinusoidal waves through a Cathode Ray Tube (CRT). Although this instrument is not one of the common instruments you will use, what it displays is very useful in the analysis of AC generation.
5.1.2.2 Sine Wave

The direction in which a conductor cuts through a magnetic field, or the direction in which a magnetic field cuts across a conductor, determines the polarity of the voltage that is induced. An easy method of showing how the polarity change is to use a graph that represents the generation of voltage over a period of time. Figure 1-24 represents the voltage induced as the conductor makes a complete rotation through the magnetic field. A sine wave is shown to coincide with the rotation of the conductor.

![Diagram of Sine Wave](image)

**Figure 1-24 – Generating a sine wave.**

5.1.2.2.1 Maximum/Peak Value

The amount of voltage or current at the maximum positive or negative point on a sine wave is called the peak value, as shown in Figure 1-25. Peak value occurs twice in each cycle: once positive and once negative. The amount represented between the positive peak and the negative peak is called the peak-to-peak value, which is simply twice the peak value.

5.1.2.2.2 Instantaneous Value

Instantaneous value is simply the value of the sine wave at any given point in time. Note that in Figure 1-25, the instantaneous value label points at three different locations of the sine wave. This is only to indicate that this value can be any point in the curve and not a fixed amount like the other values.

5.1.2.2.3 Average Value

The average value in AC is the average of all the instantaneous values during one alternation. Except for the fact that the average value is a mathematical viewpoint, it is of no great significance since it is merely a numerical average of all the sine values for all the angles. Average value is computed to be equal to 0.636 x peak value. It is always this constant.
5.1.2.4 Effective Value

Effective values for AC are often called RMS values. RMS stands for root-mean-square, which refers to the mathematical formula used to determine effective values. The formula itself is not important here. The important thing to understand is that RMS values are used to rate operating voltages on almost all AC equipment. In electrical work, you will deal mostly with effective values of voltage. Do not confuse this value, as new electricians often do, with the “average value” because the “effective value” is the actual rating of the useful power available to do work.

5.1.2.3 Cycle and Frequency

As it has been mentioned already, a complete revolution of the rotating part, called a rotor or armature, produces a positive alternation and a negative alternation, which completes a cycle. Each cycle has two maximum or peak values: one for the positive half-cycle and the other for the negative half-cycle. The number of times that this cycle is repeated over time is known as frequency. When discussing electrical frequency, the unit of time used to measure is the second. In other words, frequency is measured in cycles per second.

5.1.2.3.1 Hertz

The unit of measure for frequency is the Hertz (Hz). Figure 1-26 shows a continuous sine wave that generates a complete cycle in 0.25 seconds. In one second, four complete cycles are generated. Therefore, the frequency is 4 cycles per second, or 4 Hz. In United States, power is generated with a frequency of 60 Hz to be used in all household appliances. Some other countries generate power at a frequency of 50 Hz, and equipment used in aircrafts use 400 Hz power.

5.1.2.3.2 Frequency Formula

You can determine the frequency of the power output from a generator by using the following formula:

\[
F = \frac{P}{2} \times \frac{N}{60} = \frac{PN}{120}
\]

Where \( P \) is the number of poles and \( N \) is the speed in Revolution per Minute (RPM). For example, a two-pole, 3600-rpm generator has a frequency of \( \frac{2}{120} \times 3600 = 60 \text{Hz} \). A four-pole, 1800-rpm generator has the same frequency.

5.1.2.4 AC Generators

A generator converts mechanical energy to electrical energy. All generators can be
classified as either AC or DC, and consist of a rotating section (rotor) and a stationary section (stator). AC generators are the most common means of producing either single-phase or poly-phase power. (As a military electrician you will only be concerned with single-phase and three-phase power.) The design of the generator will determine which power is generated and from where the output is taken. One example of how a generator operates is as follows: a mechanical force is applied to the shaft of the rotating section to cause relative motion within the magnetic lines of force. The shaft turns and electrical energy in the form of voltage and current is delivered to the external circuit load via conductors.

Generators use the principle of electromagnetic induction to produce voltage and current. This principle states that if a conductor lies within a magnetic field, and either the field or the conductor moves, a voltage is induced in the conductor. When a voltage is induced, electrons move providing current flow.

5.1.2.4.1 Single Phase

A simple single-phase generator consists of one conductor and one magnetic field, as shown in Figure 1-27. As the conductor cuts the magnetic field, a voltage of varying amount and direction is generated. In a practical generator, the conductor is wound to form a coil or winding. The magnetic field is produced from other windings, or electromagnets. If you connect an oscilloscope to the output of a single-phase generator you will see a continuous sine wave like the ones discussed previously.

5.1.2.4.2 Three Phase

Three-phase electricity is widely used to power heavy equipment, i.e., motors and air conditioning systems. The majority of generators used in power plants produce three-phase electricity. These generators have three separate coils distributed uniformly around a stationary section called the “stator”. If you divide 360° (a complete circle) by three, you get 120°. This is the separation between coils as shown in the simplified generator represented in Figure 1-28.

![Figure 1-28 – Rotating magnetic field](image)

![Figure 1-29 – Three phase at 120°](image)

The black and white arrow in the center of the generator in Figure 1-27 represents a rotating magnetic field. Figure 1-28 shows the magnetic field rotating clockwise from its...
vertical position and the corresponding outputs. Keep in mind that for simplicity and to avoid confusion this figure represents the generation of power from the winding only. However, other windings would also be producing power as the rotating magnetic field passes by them. Because the windings are physically separated by 120°, the sine waves produced by each winding will be also separated by 120° as shown in Figure 1-29.

Looking at Figure 1-29, you can see that the A phase starts at 0°; the B phase starts at 120°; and the C phase starts at 240°. The other marks (90°, 180°, 360°) are shown as references with respect to the A phase.

5.1.3 Characteristics of AC Circuits

5.1.3.1 Resistance

Every material offers some resistance or opposition to the flow of current. Good conductors, such as copper, silver, and aluminum offer very little resistance. Poor conductors, or insulators, such as glass, wood and paper, offer a high resistance to current flow. The determining factors for the resistance of a conductor include the size and type of conductor material. In addition, the devices and equipment that make up an electrical circuit will offer resistance and will be referred to as the “load” in up coming areas of study.

In a purely resistive AC circuit, meaning that the load has only resistors, the relationship between current and voltage is not affected, as it will be with inductors and capacitors. To illustrate this, refer to Figure 1-30. The two sine waves represent the voltage and current through a purely resistive circuit. Note that both waves cross the zero mark at the same time and reach their peak values at the same time. When this occurs, the voltage and current in the circuit are said to be in-phase and the AC circuit will conform to the same laws as an equivalent DC circuit. This means that you can apply Ohm’s Law to find the missing variables in a circuit.

Up to this point you can see that the electrical properties for both AC and DC circuits are the same. What you are about to learn is that there are some unique characteristics that only apply to AC circuits. These characteristics are inductance and capacitance.

5.1.3.2 Inductance/Inductive Reactance

Current through an AC circuit, as you already know, reverses direction in every cycle. When using AC at 60 Hz, for example, means that current will flow in one direction for 1/120th of a second (half a cycle) and then reverse direction for the next 1/120th of a second (complete the cycle). This reversal continues for every cycle in the sine wave and for as long as current is flowing through a circuit.
Current flow through a conductor produces a magnetic field. Figure 1-31 illustrates how current flowing through a conductor (dashed line) produces a magnetic field around that conductor (arrows circling the conductor). When the conductor is formed into a coil, sometimes called an inductor or winding, the magnetic field effect is increased.

To produce a voltage you need to have a conductor, a magnetic field, and relative motion. When AC flows through a coil, or inductor, it produces a magnetic field that constantly changes polarity as current changes direction. This constant change of polarity in the magnetic field produces the same effect that relative motion of the conductor through a fixed magnetic field would have. Therefore, the three conditions to produce a voltage exist: a conductor (the coil), a magnetic field, and relative motion (constant change of polarity). The voltage generated through a coil is small compared to the current that helped generate it. However, this small voltage opposes normal current flow much like a resistor opposes current flow.

Opposition to changes in current flow is the effect that a coil has in an AC circuit. This physical property is called Inductance, and its symbol is “L”. The unit for inductance is the henry, and its symbol is “H”. Inductive reactance is the measure of the opposition to current flow that is created by inductance. Since inductive reactance, like resistance, limits current flow, it is measured in ohms. To convert the inductance of a coil given in henries to inductive reactance in ohms, the following formula is used:

$$X_L = 2\pi f L$$

$X_L$ = Inductive reactance (in ohms)

$2\pi$ = Constant

$f$ = frequency (in Hz)

$L$ = Inductance (in henries)

However, it is important to remember that inductive reactance will be associated with AC circuits that contain inductors like motor windings, transformer windings, and other coiled conductors.

Figure 1-32 shows a circuit that contains two coils, or inductors, and a resistor. Note the graphic symbol used to depict an inductor. Engineers, circuit designers and technicians use circuits like this one to calculate the combined effects of resistance and inductive reactance. Inductors L1 and L2 simulate the effects of transformer windings or motor windings. Resistor R1
simulates the total wire resistance in the circuit. This is also helpful when calculating the total current required from the generator.

As discussed before, in a purely resistive circuit the relationship between voltage and current in an AC circuit is not affected. However, in a purely inductive circuit, one that theoretically would have zero resistance and all inductance voltage and current are affected by a shift of 90° between the two sine waves, as shown in Figure 1-33. Note in the figure that the voltage sine wave starts at zero, whereas the current sine wave does not begin until the voltage sine wave has reached its peak, or 90°. This is because the inductance in the circuit opposes current flow momentarily, until the current overtakes it 90° later.

When the voltage builds up before the current as shown in Figure 1-33, it is said that the voltage leads the current. In other words, current lags the voltage. In a purely inductive circuit, voltage and current are out-of-phase by 90°.

By now you know that all materials have some resistance. Therefore, a purely inductive circuit is practically impossible. With resistance present in the circuit, the phase angle decreases.

Just like resistors and inductors offer some opposition to current flow in an AC circuit and affect the phase relationship between voltage and current, capacitors also affect an AC circuit.

5.1.3.3 Capacitance/Capacitive Reactance

Capacitors have the ability to store a charge and oppose changes in voltage. Capacitor has four stages: charging, charged, discharging, and discharged.

Figure 1-34 shows a capacitor being charged with a DC source (A) and discharging through a lamp (B). This is the example that was used in that previous unit. However, what happens when the capacitor is connected into the circuit without the switch? Figure 1-35 will be used to answer this question and to transition into the effects of a capacitor in an AC circuit. The arrows indicate the current flow from the negative side of the battery, through the capacitor and through the lamp.

The current going into the capacitor is indicated with dashed arrows to signify that
it only occurs momentarily while the capacitor is charging. Once it has charged current flow through the capacitor stops. The graph below the circuit in Figure 1-35 shows what happens to the voltage while the capacitor is charging. Notice that it does not reach the 12 V level until after the capacitor has been charged. This period of time is usually a fraction of a second that has no noticeable effect on a DC circuit and is therefore not even considered in basic circuit calculations.

Capacitors, with their ability to oppose changes in voltage, have a unique effect in AC circuits. This effect is known as Capacitance, and its symbol is “C”. Capacitance is measured in units called farads and its symbol is “F”. Capacitive reactance is the measure of the opposition to current flow caused by capacitance, or the placement of capacitors in a circuit, and is measured in ohms. To convert the capacitance in a circuit given in farads to capacitive reactance given in ohms, the following formula is used:

\[ X_C = \frac{1}{2\pi fC} \]

\( X_C \) = Capacitive reactance (in ohms)
2π = Constant
\( f \) = frequency (in Hz)
C = Capacitance (in farads)

Figure 1-36 shows a circuit with two capacitors and a resistor that could be used to simulate, for example, the capacitance between two wires lying side by side over a long distance. This is usually the job of engineers and circuit designers. However, you as a construction electrician will work with capacitors in motor circuits, power conditioning circuits, and other applications. Understanding the basic purpose of a capacitor in an AC circuit will help you when troubleshooting more complicated circuits.

Capacitance and capacitive reactance are related in the same way that inductance and inductive reactance are related. Capacitive reactance, like inductive reactance, is measured in ohms. The effects of capacitance, like the effects of inductance, cause current and voltage to be out of phase. However, the effects of capacitance are not the same as the effects of inductance. Since capacitors oppose changes in voltage, the current in a purely capacitive circuit will be ahead of the voltage.

Figure 1-36 shows how when the voltage starts to build up from zero, the current is already at its peak value, or 90° ahead of the voltage. When this occurs, it is said that the current leads the voltage or that the voltage
lags the current. In a purely capacitive circuit, voltage and current are out-of-phase by 90º.

You may have noticed that the effects of capacitance in a circuit are opposite to the effects of inductance. In fact, capacitance is often added to AC circuits to counter the effects of inductance. For example, when the inductance in a circuit would limit current flow more than a desirable amount, capacitance can be added to that circuit to bring current flow up to the level that is needed. If a circuit has 10 ohms of inductive reactance (XL), then 10 ohms of capacitive reactance (XC) would cancel the inductance out of the circuit. Think of XL as positive numbers and XC as negative numbers, they are opposite.

A purely capacitive circuit is practically nonexistent because of the added resistance of the wiring and other components of a circuit. Because of this resistance, the phase angle between voltage and current will be less than 90º, depending on the amount of resistance vs. capacitance.

Resistance, inductive reactance and capacitive reactance are all measured in ohms. Now that you know how resistance, inductance and capacitance affect voltage and current in an AC circuit individually, its time to study their combined effect—impedance.

### 5.1.3.4 Impedance

Impedance is defined as the total opposition to the flow of AC in a circuit. It is the combined effect of the total inductive reactance, capacitive reactance and resistance in an AC circuit. The symbol for impedance is the letter \( Z \), and the unit of measurement for impedance is ohms.

The total effects of impedance in a circuit can be better understood with the basic diagram shown in Figure 1-37. The three properties that make up impedance are shown in relation to the horizontal axis. Note how XL is 90º above and XC is 90º below this axis. Here you can really see how XL is in the opposite direction of XC, hence having the opposite effect. R is shown in line with the horizontal axis, meaning that it has 0º. Figure 1-37 depicts a circuit that has 10 ohms of inductive reactance and 10 ohms of resistance. The resulting impedance is shown as the line between zero and the point where the other two values intercept. The angle labeled “\( \theta \)” is the resulting angle of phase that the voltage and current will have due to the combined effects.

### 5.1.3.5 AC Power

To determine the power in an AC circuit, you must take into consideration not only the amount of current, voltage, and resistance, but the amount of inductance and capacitance as well. Because inductance and capacitance can cause AC voltage and current to be out of phase, there are three different kinds of power in AC circuits: apparent power, true power, and reactive power. Refer to Figure 1-38.
5.1.3.5.1 Apparent Power

Apparent power is the power used to do work plus the power stored during part of a cycle by inductance and capacitance and then returned to the power source. Apparent power is the voltage times the current in any circuit. (In a purely resistive circuit, apparent power and true power are the same). Refer to equations below for apparent power.

\[ S = I^2 \times Z \quad S = \frac{E^2}{Z} \quad S = I \times E \]

- **S** = Apparent Power
- **I** = Current
- **E** = Voltage
- **Z** = Impedance

Measured in units of Volt-Amps (VA)

5.1.3.5.2 True Power

True power in an AC circuit is the power actually used to do work. The power used in a purely resistive circuit is true power. True power can be determined by multiplying the voltage at any instant by the current at the same instant. If the voltage and current are in phase, their product, true power, will always be positive, since two positive numbers or two negative numbers multiplied together will always yield a positive result. When the voltage and the current are out-of-phase, at some points in time the instantaneous value of voltage may be positive while the value for current may be negative. Power, therefore, will be negative. What does this mean? This means that positive power is used by the load to do work, while negative power is reflected back to the source and being counterproductive. Refer to equations below for true power.

\[ P = I^2 \times R \quad P = \frac{E^2}{R} \]

- **P** = True Power
- **I** = Current
- **R** = Resistance
- **E** = Voltage

Measured in units of Watts

5.1.3.5.3 Power Factor

The power factor for an AC circuit is the ratio of the true power to the apparent power in that circuit. The difference between true power and apparent power is directly caused by the phase separation of the voltage and the current in an AC circuit.

5.1.3.5.4 Reactive Power

Reactive power is the type of power found in a purely inductive circuit or a purely capacitive circuit. Unlike true power, reactive power does no useful work. As defined earlier, positive power is power that goes from a power source to a load. In a purely
inductive circuit, positive power goes from the power source to the inductance. Negative power, as defined earlier, is power reflected back to the power source. In an inductive circuit, the negative power periods are those during which the power absorbed by the inductance returns to the power source as the magnetic field collapses. In a purely inductive circuit, then, power just goes back and forth between the power source and the inductance. Since no power is used to do work, there is no power that can be identified as true power. The power in a purely inductive circuit is only reactive power. The power in a purely capacitive circuit is also reactive power. When power is positive, the capacitor is charging, so it is storing up power. When the power is negative, the capacitor is discharging, (it is returning power to the source). The effect is the same for a purely capacitive circuit as the purely inductive circuit in the respect that the amount of power supplied by the power source to the capacitor is equal to the amount of power that is returned to the power source. The power in a capacitive circuit does not do any work, so it is reactive power rather than true power. Refer to equations below for reactive power.

\[ Q = I^2 \times X \]
\[ Q = \frac{E^2}{X} \]

\( Q \) = Reactive Power

\( I \) = Current

\( E \) = Voltage

\( X \) = Reactance

Measured in units of Volt-Amps-Reactive (VAR)

5.1.3.6 Harmonics of an AC Circuit

A harmonic is defined as a sinusoidal component added to a sine wave, having a frequency that is a multiple of the fundamental frequency.

When generated, an AC waveform is sinusoidal. However, when various loads are connected into the circuit, other waveforms that may not be sinusoidal are produced as a result. Non-sinusoidal waveforms are important for an electrical technician to understand. Modern digital electronics systems, such as computers, data communications radar, pulse systems and circuits requiring ramp waveforms, have an effect on the fundamental sine wave in an AC circuit. They can cause a sinusoidal wave to become non-sinusoidal. A pure AC sine wave is comprised of one single frequency. Non-sinusoidal signal waveforms can be mathematically shown to be composed of a fundamental frequency sine wave plus a number of multiples of that frequency. These multiples are called harmonics. If the sine wave is not sinusoidal, it indicates the presence of harmonics. These harmonics can be either “odd” or “even”. Odd harmonics are those that represent frequencies of 3-times, 5-times, 7-times, and so on, of the fundamental sine wave. Even harmonics are those that represent frequencies of 2-times, 4-times, 6-times, and so on, of the fundamental sine wave. Sinusoidal waveforms can be distorted because of the presence of “odd” harmonics, “even” harmonics, or a mixture of both.

Figure 1-39 is an example of the effects of having harmonics in a circuit. In this example, the third harmonic is added to the fundamental sine wave. Notice that while the fundamental wave completes one cycle, the other wave completes three cycles in the same time period, this is why is called the third harmonic.
Harmonics have a number of effects on a variety of equipment. Harmonics can cause control and monitoring equipment to register improperly. The harmonic components of voltage can affect motor and generator efficiency, and can affect the torque developed. Harmonics applied to transformers may result in increased levels of audible noise. However, the main effect of harmonics on transformers is excess heat. Harmonics can also shorten the life of capacitors by deteriorating the dielectric over time. Power electronic equipment may also be affected by harmonic distortion. Remember that harmonics are only associated with AC circuits and not with DC circuits.

6.0.0 ELECTRICAL CIRCUITS

6.1.0 Circuit Requirements and Configurations

6.1.1 Circuit Requirements

A closed loop of wire (conductor) is not necessarily a circuit. In any electric circuit where electrons move around a closed loop, current, voltage and resistance must be present. The physical pathway for current flow is actually the circuit. Its resistance controls the amount of current flow around the circuit. Therefore, at a minimum, a simple circuit must contain three things: a voltage source, some type of load, and a conducting pathway for current to flow. As an example, a lamp connected by conductors across a dry cell form a simple electric circuit as shown in Figure 1-39.

In any AC or DC electrical circuit, you know that current flows from negative (-) to positive (+). Figure 1-39 illustrates current flow in a simple DC circuit. Notice that as long as the circuit’s pathway is unbroken, it is a closed circuit and current will flow. However, if the path is broken at any point, it is an open circuit and current flow will stop.

6.1.1.1 Voltage Source

As previously stated every electrical circuit must have a voltage source. The most common source of voltage is either through generators (AC/DC) or batteries.

6.1.1.1.1 Generator

An AC generator provides much larger power and voltage ratings than DC generators. By producing alternating current, the voltage can be stepped up or stepped down efficiently by the use of transformers.

6.1.1.2 Battery

A battery is a good example of a direct-current power supply. Power and voltage control is limited with this type of power source. Voltage control with DC power is complicated.
and can not be changed with transformers. Therefore, it is not widely used where large amounts of power are needed.

6.1.1.2 Conductor
Every electrical circuit must have conductors to connect the other components of the circuit. The conductors create a complete electrical path for current to flow.

6.1.1.3 Resistive Load
A resistive load is required to drop the voltage and/or restrict current flow. A lamp is one example of a resistive load.

6.1.1.4 Complete Path(s) for Current Flow
For current to flow, there must always be a complete electrical path. A complete path allows the current to return to its place of origin, whether it be a battery or a generator.

6.1.2 Configuration Identification

6.1.2.1 Series Circuit
A series circuit is defined as two or more units of resistance connected end to end to form only one path for current flow and an AC or a DC voltage source. The series circuit in Figure 1-40 contains two resistors and one voltage source. Each resistor is labeled with an "R", the symbol for resistance. In addition, each "R" is followed by a numeral to identify (called a subscript) the specific resistor (R1, R2, etc.).

Subscripts are numbers or letters written below and to the right of the original circuit function letter, as in R₁ or R₂. Total circuit values are normally identified with a subscript "t". Total voltage, total current and total resistance is identified as Eₜ, Iₜ, and Rₜ.

6.1.2.2 Parallel Circuit
A parallel circuit is defined as having more than one current path connected to a common voltage source. Parallel circuits must contain two or more resistors, which are not connected in series. An example of a basic parallel circuit is shown in Figure 1-41. Starting at the voltage source (Eₜ) and tracing counterclockwise around the circuit, two complete and separate paths can be identified in which current can flow. One path is traced from the source through resistance R₁ and back to the source: the other, from the source through resistance R₂ and back to the source.

Figure 1-40 – Series AC circuit.

Figure 1-41 – Parallel circuit.
6.1.2.2.1 Multiple Paths for Current Flow

A parallel circuit must contain at least (can have more) two paths for current flow. All of these paths must return to the same voltage source.

6.1.2.2.2 Number of Paths = Number of Resistors

Each path for current flow must contain only one resistor for the circuit to be considered a parallel circuit. The circuit is considered a true parallel circuit when the number of current paths equals the number of resistors.

6.1.2.3 Series Parallel Circuit

A series parallel electrical circuit is defined as a circuit that contains more than one path of current flow and at least two resistors in series in one of the paths. Keep in mind; each path must contain at least one resistor and one path with at least two, so there will always be more resistors than paths for current flow. Figure 1-42 shows an example of a series parallel circuit. Remember that current in an AC circuit changes direction continuously. To study the paths of current flowing in the circuit of Figure 1-41, an instant in time is taken when the current is flowing in one direction. Total current in the circuit is indicated by \( I_t \). This current leaves the generator from the top towards point A. From point A, \( I_t \) has two paths: down through \( R_1 \) and to the right towards \( R_2 \) and \( R_3 \) the series branch. These currents are labeled \( I_1 \) and \( I_2 \). Mathematically stated, \( I_t = I_1 + I_2 \). It should be noted that the values of \( I_1 \) and \( I_2 \) depend on the resistance of each path.

Towards the bottom of Figure 1-42, currents \( I_1 \) and \( I_2 \) will join at point B to become \( I_t \) again, returning to the bottom of the generator. When current reverses polarity during the second half of the sine wave, current will leave the generator from the bottom towards point B, split again, and then rejoin at point A to return to the top of the generator.

![Series parallel circuit diagram](image)

**Figure 1-42 – Series parallel circuit.**

7.0.0 ELECTRICAL CIRCUIT COMPUTATIONS

7.1.0 Series Circuit Computations

When performing calculations to determine electrical property values in circuits containing two or more components, it becomes necessary to use subscripts to identify specific components. By knowing any two of the three electrical property quantities, i.e., voltage and current, the third (resistance) may be determined mathematically using Ohm’s Law. However, you can also apply Kirchoff’s Voltage and Current Laws in some instances.
7.1.1 Kirchoff’s Voltage Law (E)

The voltage drop across a resistor in a simple circuit is the total voltage across the circuit and is equal to the applied voltage. The total voltage drop across a series circuit is also equal to the applied voltage. In any series circuit, the SUM of the voltage drops must equal the total voltage. The formula, which expresses this relation, is:

$$E_t = E_1 + E_2 + E_3 + \ldots + E_N$$

It must be emphasized that the potential difference across a resistor remains constant as it is a measure of the amount of energy required to move a unit charge from one point to another. As long as the source produces electric energy as rapidly as it is consumed in a resistance, the potential difference across the resistance will remain at a constant voltage. The applied voltage and the proportional relationship of each resistance in the circuit determine the value of this voltage. The voltage drops that occur in a series circuit are in direct proportions to the resistance across which they appear. This is a result of having the same current flow through each resistor. Thus, the larger the resistor the larger will be the voltage drop across it. The current in a series circuit, in completing its electrical path, must flow through each resistive load inserted into the circuit.

7.1.2 Kirchoff’s Current Law (I)

As stated previously, a series circuit is defined as two or more units of resistance connected end to end to form only one path for current flow. Current will only have one path to follow. Current flow in the series circuit is the same throughout the circuit, so the value of current flowing through any resistor ($I_1, I_2, I_3, \text{etc.}$) is equal to the value of total current ($I_t$).

The formula, which expresses this relation, is:

$$I_t = I_1 = I_2 = I_3 = \ldots = I_N$$

7.1.3 Resistance Law (R)

Since the current flow will only take one path through the series circuit, it will have to travel through all of the resistors in the circuit. Therefore, the individual resistors will work to limit current flow. The total resistance of the circuit will be equal to the sum of the individual resistances. This statement can be expressed in equation form as:

$$R_t = R_1 + R_2 + R_3 + \ldots + R_N$$

It should be noted here that although these laws mention only resistance, the meaning of the word should be understood to mean a load in the circuit that may not be purely resistive. Previously you learned how inductive and capacitive loads could be measured in ohms ($X_L$ and $X_C$).

7.1.4 Power Law (P)

Each resistor, or load, in a series circuit consumes power to do work and some of it is dissipated in the form of heat. Since this power must come from the source, the total power must be equal in amount to the power consumed by the circuit resistance. In a series circuit, the total power is equal to the SUM of the powers dissipated by the individual resistors. In equation form:

$$P_t = P_1 + P_2 + P_3 \ldots + P_N$$
7.2.0 Parallele Circuit Computations

7.2.1 Kirchoff’s Voltage Law (E)

You have seen that the source voltage in a series circuit divides proportionately across each resistor in the circuit. In a parallel circuit, the same voltage is present across all the resistors of a parallel circuit. This voltage is equal to the applied voltage \( E_t \). This statement can be expressed in equation form as:

\[
E_t = E_1 = E_2 = E_3 = \ldots E_N
\]

Note that Kirchoff’s voltage law for parallel circuits is similar to Kirchoff’s current law for a series circuit.

7.2.2 Kirchoff’s Current Law (I)

The current in a circuit is inversely proportional to the circuit resistance. This fact establishes the relationship upon which the following discussion is developed. A single current flows in a series circuit. The total resistance of the circuit determines its value. However, the source current in a parallel circuit is distributed among the available paths or branches in relation to the value of the resistors in each branch. The characteristics of current in a parallel circuit can be expressed in terms of the following equation:

\[
I_t = I_1 + I_2 + I_3 + \ldots I_N
\]

Note again that Kirchoff’s current law for parallel circuits is similar to Kirchoff’s voltage law for series circuits. Make sure you know the differences so you will not confuse the laws for series circuits and parallel circuits.

7.2.3 Resistance Law (R)

The total resistance of a parallel circuit will always be less than the smallest resistor in the circuit. This stems directly from Ohm’s Law where resistance is directly proportional to voltage and inversely proportional to current. In relation to current this means that, when voltage is constant, as current increases resistance must be decreasing in the (parallel) circuit. Scientists like Ohm and Kirchoff developed the formula to express total resistance in a parallel circuit as follows:

\[
R_t = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots + \frac{1}{R_n}}
\]

In words this equation states that the total resistance in a parallel circuit is equal to the inverse value of the addition of the inverses of individual resistors (loads) in the circuit. If, for example, you have three resistors of 30 ohms each connected in parallel, the total resistance of the circuit would be expressed as follows:

\[
R_t = \frac{1}{\frac{1}{30} + \frac{1}{30} + \frac{1}{30}}
\]

Working with the bottom operation of the equation first, you would need to find a common denominator for 30. Since all resistors have the same value, the common denominator would be this same value of 30:

\[
\frac{1}{30} + \frac{1}{30} + \frac{1}{30} = \frac{3}{30} = \frac{1}{10} \text{ (simplified)}
\]

The top operation of the equation, the one by itself, is only indicating that when the bottom operation is executed the final value is inverted. For this example, the \( \frac{1}{10} \) will become 10/1, which is equal to simply 10, or in this case 10 ohms of resistance. Note
that although there are three 30-ohm resistors in the circuit, the total resistance is only 10 ohms. From this formula and knowing that in a parallel circuit where all the resistors have the same value, the common denominator will always be the value of the resistors. Therefore, this formula for parallel circuits with resistors of the same value can be simplified to:

\[ R_t = \frac{R}{N} \]

Where \( R_t \) represents total resistance; \( R \) represents the value of the resistors; and \( N \) represents the number of resistors in the circuit.

**7.2.4 Power Law (P)**

Power computations in a parallel circuit are essentially the same as those used for the series circuit. The total power dissipated is equal to the sum of the powers dissipated by the individual resistors. Like the series circuit, the total power consumed by the parallel circuit is expressed by the formula:

\[ P_t = P_1 + P_2 + P_3 \ldots P_N \]

**7.3.0 Series Parallel Combination**

The basic technique used for solving dc combination-circuit problems is the use of equivalent circuits. To simplify a complex circuit to a simple circuit containing only one load, equivalent circuits are substituted (on paper) for the complex circuit they represent. To demonstrate the method used to solve combination circuit problems, the network shown in Figure 1-43 will be used to calculate various circuit quantities, such as resistance, current, voltage, and power.

Examination of the circuit shows that the only quantity that can be computed with the given information is the equivalent resistance of \( R_2 \) and \( R_3 \).

*Figure 1-43 – Example combination circuit.*
Given:  
\( R_2 = 20\Omega \)  
\( R_3 = 30\Omega \)

Solution:  
\[ R_{eq1} = \frac{R_2 \times R_3}{R_2 + R_3} \]
\[ R_{eq1} = \frac{20\Omega \times 30\Omega}{20\Omega + 30\Omega} \]
\[ R_{eq1} = 12\Omega \]

Now that the equivalent resistance for \( R_2 \) and \( R_3 \) has been calculated, the circuit can be redrawn as a series circuit as shown in Figure 1-44.

Given:  
\( R_1 = 8\Omega \)  
\( R_{eq1} = 12\Omega \)

Solution:  
\[ R_{eq} = R_1 + R_{eq1} \]
\[ R_{eq} = 8\Omega + 12\Omega \]
\[ R_{eq} = 20\Omega \text{ Or } R_T = 20\Omega \]

The original circuit can be redrawn with a single resistor that represents the equivalent resistance of the entire circuit as shown in Figure 1-45.

To find total current in the circuit:

Given:  
\( E_S = 60V \)  
\( R_T = 20\Omega \)
Solution: \[ IT = \frac{ES}{RT} \]

\[ IT = \frac{60V}{20\Omega} \]

\[ IT = 3A \]

To find total power in the circuit:

Given: \( ES = 60V \)
\( IT = 3A \)

Solution: \[ PT = ES \times IT \]

\[ PT = 60V \times 3A \]

\[ PT = 180W \]

To find the voltage dropped across \( R_1, R_2, \) and \( R_3 \), refer to Figure 1-45. \( Req_1 \) represents the parallel network of \( R_2 \) and \( R_3 \). Since the voltage across each branch of a parallel circuit is equal, the voltage across \( Req_1 \) (\( Eeq_1 \)) will be equal to the voltage across \( R_2 \) (\( ER_2 \)) and also equal to the voltage across \( R_3 \) (\( ER_3 \)).

Given: \( IT = 3A \)
\( R_1 = 8\Omega \)
\( Req_1 = 12\Omega \)

Solution: \[ ER_1 = I_1 \times R_1 \]
\[ ER_1 = 3A \times 8\Omega \]
\[ ER_1 = 24V \]
\[ ER_2 = ER_3 = Eeq_1 \]
\[ Eeq_1 = IT \times Req_1 \]
\[ Eeq_1 = 3A \times 12\Omega \]
\[ Eeq_1 = 36V \]
\[ ER_2 = 36V \]
\[ ER_3 = 36V \]

To find power used by \( R_1 \):

Given: \( ER_1 = 24V \)
\( IT = 3A \)
Solution:  
\[ \text{PR}_1 = \text{ER}_1 \times \text{IT} \]  
\[ \text{PR}_1 = 24\text{V} \times 3\text{A} \]  
\[ \text{PR}_1 = 72\text{W} \]

To find the current through R2 and R3, refer to the original circuit, Figure 1-43. You know ER2 and ER3 from previous calculation.

Given:  
\[ \text{ER}_2 = 36\text{V} \]  
\[ \text{ER}_3 = 36\text{V} \]  
\[ \text{R}_2 = 20\Omega \]  
\[ \text{R}_3 = 20\Omega \]  

Solution:  
\[ \text{IR}_2 = \frac{\text{ER}_2}{\text{R}_2} \]  
\[ \text{IR}_2 = \frac{36\text{V}}{20\Omega} \]  
\[ \text{IR}_2 = 1.8\text{A} \]  
\[ \text{IR}_3 = \frac{\text{ER}_3}{\text{R}_3} \]  
\[ \text{IR}_3 = \frac{36\text{V}}{30\Omega} \]  
\[ \text{IR}_3 = 1.2\text{A} \]

To find power used by R2 and R3, using values from previous calculations:

Given:  
\[ \text{ER}_2 = 36\text{V} \]  
\[ \text{ER}_3 = 36\text{V} \]  
\[ \text{IR}_2 = 1.8\text{A} \]  
\[ \text{IR}_3 = 1.2\text{A} \]  

Solution:  
\[ \text{PR}_2 = \text{ER}_2 \times \text{IR}_2 \]  
\[ \text{PR}_2 = 36\text{V} \times 1.8\text{A} \]  
\[ \text{PR}_2 = 64.8\text{W} \]  
\[ \text{PR}_3 = \text{ER}_3 \times \text{IR}_3 \]  
\[ \text{PR}_3 = 36\text{V} \times 1.2\text{A} \]  
\[ \text{PR}_3 = 43.2\text{W} \]

**Test your Knowledge (Select the Correct Response)**

4. Calculate the total amperage of a parallel circuit with the following values provided? (I_1 = 3\text{mA}, I_2 = 6\text{mA}, I_3 = 4\text{mA})

A. 11\text{mA}  
B. 13\text{mA}  
C. 24\text{mA}  
D. 36\text{mA}
**8.0.0 CONSTRUCTING an ELECTRICAL CIRCUIT**

**8.1.0 Construction of a Series Circuit**

When you construct a series circuit, you need to follow a wiring diagram or schematic drawing of some kind. It could be provided by an electrical engineer or a manufacturer. The important point to remember is to start at one point and systematically follow the drawing until you have all components built into your circuit.

**8.1.1 Voltage Source**

A voltage source, which can be a battery or a generator, is required to provide the electrical pressure to generate current flow. This voltage source will supply the power necessary to do work. Refer to Figure 1-46.

**8.1.2 Overcurrent Protection**

A fuse or circuit breaker is required to protect the conductors and the load. The overcurrent protection device, whether it is a fuse or a circuit breaker, must be sized according to the current flow (load) required by the equipment being connected. Overcurrent protection is connected in series with the circuit. The power supply provides power to the “input” side of the breaker or fuse and equipment is connected to the “load” side. Refer to Figure 1-47.

**8.1.3 Switch**

Most electrical circuits require some means of turning on or shutting off power to them. You accomplish this daily by turning on and off lights, air conditioners, or even the ignition on your car. Switches allow you start or stop the flow of power to electrical equipment by physically opening or closing the circuit. Switches are connected in series within the circuit and must be installed on the ungrounded conductor. A switch must also be rated according to the current flow and voltage generated by the power supply. Refer to Figure 1-48.

**8.1.4 Resistive Load**

The load limits current flow. It is electrical equipment, such as a light bulb or hair-dryer motor that actually accomplishes the useful work. Equipment can be as simple as a clothes iron or as complicated as a computer. In a series circuit, the resistors (load) are connected end-to-end. Refer to Figure 1-49.
8.1.5 Conductors

Current requires an electrical path to keep flowing. Without a complete path, current will not flow. The conductors provide the physical connection between the power source, overcurrent protection, switch, and the load and provide a return path back through the components so that current can flow back to its place of origin. Like the overcurrent protection devices and switch, conductors must also be rated according to the current flow and voltage generated by the power supply. Refer to Figure 1-50.

8.2.0 Construction of a Parallel Circuit

Constructing a parallel circuit is very similar to constructing a series circuit. You need a power source, conductors, and at least two resistors or loads not connected in series in at least two paths for the current to flow. All paths must return to the same voltage source. The difference is that you connect the resistors in parallel, or side-by-side, instead of end-to-end as in the series circuit. Ensure power is off before constructing any circuit.

8.2.1 Voltage Source

As with the series circuit, a parallel circuit requires a voltage source to provide the electrical pressure needed to generate current flow. Connections are the same as in the series circuit.

8.2.2 Overcurrent Protection

Like all electrical circuits, parallel circuits require some sort of overcurrent protection. Overcurrent protection connections are the same for parallel circuits as for series circuits. The overcurrent protection is connected immediately after the power supply and in line (in series) with the circuit. It is important to note that even though you are constructing a parallel circuit, the circuit breaker or fuse must be placed in series. If it is placed in parallel, then current will have another path to flow, bypassing the protective device.

8.2.3 Switch

As stated earlier, electrical circuits require a switch to provide a means of opening or closing the circuit. Switch connections for parallel circuits are the same as for series circuits. Switches are connected in series within the circuit and must be installed on the ungrounded conductor.

8.2.4 Junction(s)

Junctions in a parallel circuit are used where three or more conductors meet each other. At a junction, the current splits into the individual branch conductors that feed their respective resistive loads.

8.2.5 Resistive Load

As stated before, the load is what will be limiting current flow in the electrical circuit. In a parallel circuit, the number of resistors equals the number of current paths. The minimum number of resistive loads needed for a parallel circuit is two. The resistive loads are connected in parallel.
8.2.6 Conductors
Conductors are required in parallel circuits just as they are in series circuits. These conductors provide the means for current to flow through the circuit to electrical equipment and return to the power source.

8.3.0 Construction of Series Parallel Combination Circuit
Constructing a series-parallel circuit is very similar to constructing a series and parallel circuits. You still require a power source, conductors containing more than one path of current flow and at least two resistors in series in one of those paths. Keep in mind, each path must contain at least one resistor and one path with at least two, so there will always be more resistors than paths for current flow. All paths must return to the same voltage source. Resistors are connected in parallel, or side-by-side, and end-to-end as in the series circuit. Ensure power is off before constructing any circuit. Review series and parallel circuit construction.

Summary
Your knowledge and use of basic mathematical skills and electrical theory is essential for the safe conduct and completion of your job as a Construction Electrician. Basic mathematical skills includes addition, subtraction, multiplication, and division of whole numbers, fractions, and decimals. It is not only important to know how to use this skill, but also be knowledgeable of the results of erroneous results. Another important knowledge is the understanding and application of electrical theory. As a Construction Electrician, you need the knowledge of the concepts and principles when dealing with alternating and direct current. During your career as a Construction Electrician, you will apply this and other electrical and electronic theory in your everyday conduct.
Review Questions (Select the Correct Response)

1. Calculation of voltage per Ohm’s Law is accomplished by using which of the following formulas?
   
   A. $E = I + R$
   B. $E = \frac{I}{R}$
   C. $E = I \times R$
   D. $E = I - R$

2. Which of the following is the correct unit of measurement for current?
   
   A. Volt
   B. Amp
   C. Ohm
   D. Watt

3. Opposition to current flow best describes which of the following terms?
   
   A. Current
   B. Power
   C. Resistance
   D. Voltage

4. Which of the following symbols represents rheostat?

   A.  
   B.  
   C.  
   D.  

5. Nucleus of an atom contains what type of charge?
   
   A. Positive
   B. Negative
   C. Neutral
   D. Modulating

6. Uniform movement of electrons in a specific direction is known as what?
   
   A. Resistance Factor
   B. Current Flow
   C. Voltage Peak
   D. Power Wattage
7. How many electrons in a valence rings is called a good conductor?
   A. 2  
   B. 4  
   C. 6  
   D. 8  

8. Which of the following has NO effect on current?
   A. Magnetism  
   B. Air Pressure  
   C. Heat  
   D. Chemical  

9. Increase in voltage in a circuit will cause current to what?
   A. Decrease  
   B. Stay the same  
   C. Increase  
   D. Fluctuate  

10. Which of the following statements is true?
    A. Current is inversely proportional to resistance.  
    B. Current is inversely proportional to voltage.  
    C. Smaller the conductor, the least resistance to current flow.  
    D. As temperature of conductor rises, resistance decreases.  

11. How does a battery produce Direct Current?
    A. Mechanical energy to chemical energy  
    B. Mechanical energy to electrical energy  
    C. Chemical energy to electrical energy  
    D. Electrical energy to mechanical energy  

12. What is another name for secondary cell batteries?
    A. Dispensers  
    B. Accumulators  
    C. Dry Cell  
    D. Paste  

13. Conductor must be moved in what direction to produce electricity in a DC generator?
    A. Parallel  
    B. No motion needed  
    C. Diagonally  
    D. Perpendicular
14. **(True or False)** DC is a constant output that does not vary with respect to time.
   
   A. True  
   B. False

15. What type of test equipment is utilized to measure AC in a sine wave format?
   
   A. Frequency Counter  
   B. Oscilloscope  
   C. Multimeters  
   D. Ohmmeter

16. What term is utilized when the amount of voltage reaches the maximum positive position on a sine wave?
   
   A. Instantaneous Value  
   B. Average Value  
   C. Peak Value  
   D. Effective Value

17. Effective value is also known as which of the following terms?
   
   A. EMF  
   B. VAC  
   C. VDC  
   D. RMS

18. How long does it take to complete one continuous sine wave?
   
   A. 0.25 seconds  
   B. 0.50 seconds  
   C. 0.75 seconds  
   D. 1 second

19. Which of the following principles does an AC generator used to generate current?
   
   A. Electrohydraulic  
   B. Electromagnetic  
   C. Electrochemical  
   D. Electromechanical

20. When a conductor is formed into a coil it becomes which of the following electrical items?
   
   A. Inductor  
   B. Capacitor  
   C. Diode  
   D. Transistor
21. What is the symbol for Inductance?
   A. I  
   B. H  
   C. F  
   D. L

22. How many stages does a capacitor perform?
   A. 1  
   B. 2  
   C. 3  
   D. 4

23. What unit of measurement is used for capacitance?
   A. Volt  
   B. Farad  
   C. Henry  
   D. Ohm

24. Capacitive reactance is measured in what?
   A. Volt  
   B. Farad  
   C. Henry  
   D. Ohm

25. What is defined as the total opposition to flow in an AC circuit?
   A. Resistance  
   B. Opposition  
   C. Impedance  
   D. Inductance

26. (True/False) Apparent power is the voltage times the current in any circuit.
   A. True  
   B. False

27. Which type of electrical equipment used for overcurrent protection?
   A. Battery  
   B. Resistor  
   C. Circuit breaker  
   D. Diode
28. Based on the number 14,607, the numeral 4 is in what place?
   A. Tens  
   B. Thousands  
   C. Units  
   D. Hundreds

29. What is the sum of 54.32 and 1.786?
   A. 72.18  
   B. 56.106  
   C. 64.143  
   D. 54.498

30. What is the difference between 65.43 and 2.897?
   A. 36.46  
   B. 98.993  
   C. 62.533  
   D. 65.14

31. What is the product of 21.34 and 5.964?
   A. 127.271  
   B. 1272.71  
   C. 127.422  
   D. 1274.22

32. What is the result of dividing 246.81 by 12.3?
   A. 0498  
   B. 4.983  
   C. 2.007  
   D. 20.07

For questions 33 and 34, is the fraction on the right the lowest term for each fraction on the left?

33. \( \frac{6}{16} = \frac{2}{8} \)
   A. True  
   B. False

34. \( \frac{4}{8} = \frac{1}{2} \)
   A. True  
   B. False
For questions 35 through 36, identify the lowest common denominator for each set of fractions.

35. 2/6 and 3/4
   A. 12
   B. 10
   C. 8
   D. 6

36. 1/4 and 3/16
   A. 12
   B. 14
   C. 16
   D. 18

For questions 37 and 38, add the following fractions. Identify the correct sum in its lowest terms.

37. 2/16 + 1/4
   A. 6/16
   B. 4/16
   C. 3/8
   D. 1/8

38. 9/12 + 2/8
   A. 1 1/20
   B. 1
   C. 4/4
   D. 3/4

For questions 39 and 40, subtract the following fractions. Identify the correct difference in its lowest terms.

39. 4/9 - 1/3
   A. 3/6
   B. 1/9
   C. 1/2
   D. 3/9

40. 6/8 – 1/4
   A. 5/4
   B. 1 1/4
   C. 2/4
   D. 1/2
For questions 41 and 42, multiply the following fractions. Identify the correct product in its lowest terms.

41. \( \frac{3}{4} \times \frac{5}{8} = \)
   A. 1 5/8
   B. 1 7/8
   C. 3 3/4
   D. 15/32

42. \( \frac{8}{16} \times \frac{32}{64} = \)
   A. 1/4
   B. 256/64
   C. 4
   D. 256/16

For question 43, divide the following fractions. Identify the correct quotient in its lowest terms.

43. \( \frac{5}{8} \div \frac{1}{2} = \)
   A. 10/8
   B. 5/8
   C. 8/10
   D. 1 1/4

44. On a scale drawing, if 1/4 of an inch represents a distance of 1 foot, what length does a line on the drawing measuring 8 1/2 inches long represent?
   A. 34 feet
   B. 36 feet
   C. 38 feet
   D. 40 feet

For questions 45 and 46, is the decimal on the right the same as the fraction on the left?

45. Is \( \frac{7}{8} = 0.875? \)
   A. True
   B. False

46. Is \( \frac{2}{5} = 0.67? \)
   A. True
   B. False
For questions 47 and 48, is the measurement in inches the same as the measurement in feet?

47. 9 inches = .95 feet
   A. True
   B. False

48. 10 inches = .83 feet
   A. True
   B. False

49. If you have 50 Construction Electricians (CEs) and 10 Steel Workers (SWs), what is the ratio of SWs to CEs in simplest terms?
   A. 50:10
   B. 10:50
   C. 5:1
   D. 1:5

50. What percent of 8 is 6?
   A. 25%
   B. 33%
   C. 50%
   D. 75%

51. What is 33% of 120?
   A. 39.6
   B. 40.0
   C. 41.2
   D. 42.3

52. What is the square root of 8?
   A. 2.835
   B. 2.828
   C. 2.913
   D. 2.924
Use the ruler shown below to answer questions 53 and 54.

53. What mark is A at?
   A. 1/4 inch
   B. 1/2 inch
   C. 1/16 inch
   D. 1/8 inch

54. What mark is C at?
   A. 1/16 inch
   B. 5/16 inch
   C. 15/16 inch
   D. 1 5/16 inch

Use the ruler shown below to answer question 55.

55. What mark is the arrow B at?
   A. 42 cm
   B. 4.2 cm
   C. 4.2 mm
   D. 420 mm

56. What is the term for a straight line through a circle that runs from one point on the outside of the circle to another point directly on the outside of the circle?
   A. Circumference
   B. Radius
   C. Area
   D. Diameter
57. The area of a rectangle that is 8 feet long and 4 feet wide is
   A. 12 sq ft
   B. 22 sq ft
   C. 32 sq ft
   D. 36 sq ft

58. The area of a circle with a 14 foot diameter is
   A. 15.44 sq ft
   B. 153.86 sq ft
   C. 43.96 sq ft
   D. 196 sq ft

59. The area of a triangle with a base of 4 feet and a height of 6 feet is
   A. 36 sq ft
   B. 32 sq ft
   C. 24 sq ft
   D. 12 sq ft

60. If a concrete block measures 17 feet square and is 6 inches thick, its volume is
   A. 144.5 cu yd
   B. 5.35 cu yd
   C. 102 cu yd
   D. 3.77 cu yd

61. The volume of a 3 centimeter cube is
   A. 6 cu cm
   B. 9 cu cm
   C. 12 cu cm
   D. 27 cu cm

62. The volume of a cylinder that is 6 centimeters in diameter and 60 centimeters high is
   A. 1130.4 cu cm
   B. 1810.6 cu cm
   C. 1695.6 cu cm
   D. 6728.4 cu cm

63. The volume of a triangular shape that has a 6 inch base, a 2 inch height, and a 4 inch length is
   A. 12 sq in
   B. 24 cu in
   C. 48 sq in
   D. 36 cu in
### Trade Terms Introduced in this Chapter

<table>
<thead>
<tr>
<th>Term</th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td><strong>Angle</strong></td>
<td>The figure formed by two rays (lines) sharing a common endpoint.</td>
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<tr>
<td><strong>Architect's scale</strong></td>
<td>An architect's scale is a specialized ruler. It is used in making or measuring from reduced scale drawings, such as blueprints and floor plans. It is marked with a range of calibrated scales (ratios).</td>
</tr>
<tr>
<td><strong>Circumference</strong></td>
<td>The distance around a closed curve. Circumference is a kind of perimeter.</td>
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<td><strong>Common denominator</strong></td>
<td>An integer that is a multiple of the denominators of two or more fractions.</td>
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<tr>
<td><strong>Denominator</strong></td>
<td>The name for the bottom part of a fraction. It indicates how many equal parts make up a whole.</td>
</tr>
<tr>
<td><strong>Diameter</strong></td>
<td>Any straight line segment that passes through the center of the circle and whose endpoints are on the circle.</td>
</tr>
<tr>
<td><strong>Digits</strong></td>
<td>A symbol used in numerals to represent numbers in positional numeral systems.</td>
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<tr>
<td><strong>Improper fraction</strong></td>
<td>The absolute value of the numerator is greater than or equal to the absolute value of the denominator.</td>
</tr>
<tr>
<td><strong>Lowest common denominator</strong></td>
<td>The least common multiple of the denominators of a set of fractions. The smallest positive integer that is a multiple of the denominators.</td>
</tr>
<tr>
<td><strong>Metric ruler</strong></td>
<td>A ruler used for measuring with the metric system, generally divided into centimeters and millimeters.</td>
</tr>
<tr>
<td><strong>Mixed number</strong></td>
<td>The sum of a whole number and a proper fraction, such as 1 2/3.</td>
</tr>
</tbody>
</table>
### Negative numbers
A number that is less than zero, such as −2.

### Numerator
The name for the top part of a fraction. It indicates how many parts of a whole you are working with.

### Place value
A numeral system in which each position is related to the next by a constant multiplier, such as 10.

<table>
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<th></th>
<th>Millions</th>
<th>Hundred Thousands</th>
<th>Ten Thousands</th>
<th>Thousands</th>
<th>Hundred</th>
<th>Tens</th>
<th>Units</th>
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<tr>
<td>1</td>
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<td>7</td>
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</tbody>
</table>

### Positive numbers
A number that is greater than 0, such as 2.

### Protractor
A circular or semicircular tool for measuring an angle or a circle. The units of measurement used are generally degrees.

### Radius
Any line segment from the center of a circle to its perimeter.

### Standard (English) ruler
A ruler used for measuring with the English system, generally divided into inches, 1/2 inches, 1/4 inches, 1/8 inches, and 1/16 inches. Some standard rulers are further divided into 1/32 inches and 1/64 inches.

### Vertex
The point where two rays (line segments) begin or meet.
Additional Resources and References

This chapter is intended to present thorough resources for task training. The following reference works are suggested for further study. This is optional material for continued education rather than for task training.

Unified Facilities Criteria (UFC) 3-560-01 (Electrical Safety, Operation and Maintenance)

OSHA Regulations (Standards – 29 CFR)


Cranes and Attachments 1, SCBT 540.1, Naval Construction Training Center, Gulfport, MS, 1988.

NAVEDTRA 14167 Naval Safety Supervisor

www.line-man.com
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